Capitalization of groundwater restrictions and woody encroachment in agricultural land values across Kansas.

by

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Abstract

Kansas spans a diverse range of agricultural landscapes. In the west, semi-arid cropland relies on irrigation from the declining High Plains Aquifer. In contrast, the eastern Flint Hills are dominated by native grasslands, where increasing woody plant cover is reducing grassland productivity and posing a risk to the livestock industry that supports the region's agricultural economy. This thesis examines both regions in two different essays and evaluates how water curtailment policies and woody encroachment are capitalized into agricultural land values across the state.

The first essay evaluates how groundwater curtailment policies affect irrigated cropland values in Kansas. This study assesses how the irrigated land market capitalizes the value of groundwater restriction policies, and how alternative policy designs and objectives differ in land value effects. We find that transactions within the state-imposed Walnut Creek Intensive Groundwater Unit Control Area (IGUCA), which was put in place in response to conflicts between agricultural irrigators and wildlife habitat, are discounted by as much as 18-19% whereas the locally driven Sheridan 6 Locally Enhanced Management Area (LEMA) shows no significant effect. Our results demonstrate that the capitalization effect can vary significantly based on the policy's purpose and governance.

The second essay examines the capitalization of woody cover into grassland transaction prices across major Kansas ecoregions using a hedonic pricing framework, with complementary survey evidence on stakeholder perspectives of woody encroachment. Together, the survey and hedonic price model results provide evidence for the complex nature of woody encroachment valuation in the Kansas grassland market. Survey results suggest a disconnect between the level of concern regarding woody encroachment and the observed economic impact. While most

respondents view woody encroachment as a moderate to serious issue, they generally have not seen it affect pasture values or rental rates. Instead, the main obstacles to managing encroachment are the cost of control and limited availability of labor. We find that woody cover is capitalized positively into Kansas grassland transactions at currently observed levels of woody cover, with a one-percent increase in woody cover on a parcel associated with a 0.7% increase in transaction price per acre averages. These findings suggest that private market incentives alone are unlikely to motivate sufficient encroachment control, providing justification for public conservation programs such as the Kansas Great Plains Grassland Initiative (KGPGI).

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Preface

Agricultural land is among the most complex assets in rural economics, bundling not only physical and regulatory attributes but also non-market characteristics such as environmental amenities into a single transaction price. When a parcel of farmland is transacted, the observed price reflects everything the buyer and seller collectively know about the land's productive potential, from soil, water access, climate, and regulatory environment, as well as any non-market utility a buyer may derive from specific parcel attributes. In this sense, land markets serve as evidence of how the market values individual property characteristics for which no traditional market exists.

Kansas provides a particularly informative setting for examining how environmental attributes are capitalized into agricultural land values. The state spans a dramatic geographic and ecological gradient, from the semi-arid High Plains of the west, where the economy depends on irrigated agriculture supplied by groundwater resources, to the native grasslands of the Flint Hills, Smoky Hills, and Red Hills in the central and eastern portions of the state, where rangeland productivity and livestock operations define the agricultural economy. Across the state, the environmental factors that drive land value differ substantially. In the west, water availability and regulatory access play important roles in determining irrigated land values. Conversely, vegetation composition, grazing capacity, and ecological integrity are fundamental features in grassland valuations. As a result, understanding how land markets respond to environmental change requires accounting for the specific resource conditions and institutional policies of each region.

Despite the differences across the state's landscape, the two essays in this thesis are united by a common methodological approach and a common underlying question. Both apply the hedonic pricing framework, formalized by Rosen (1974), which treats observed transaction prices as the outcome of a competitive market that implicitly values the full bundle of attributes a parcel carries. By examining transaction-level sales data, both essays exploit parcel-level variation in environmental conditions and regulatory exposure to identify how specific attributes are reflected in land's market value. The chapters of this thesis are united by a common theme: how do agricultural land markets respond when the natural resource characteristics that underly productivity change?

The findings from both essays carry practical relevance beyond Kansas. Groundwater depletion and woody encroachment are not uniquely Kansas problems; they are challenges facing agricultural producers and communities across the Great Plains and the broader semi-arid regions of the United States. Understanding how land markets price these conditions is important for water managers designing conservation programs, rangeland conservationists evaluating the reach and need of public programs, and agricultural lenders and appraisers who must account for environmental changes in land valuations.

Essay 1 – Land Value Impact of Water Curtailment Policies in Kansas

Chapter 1 - Introduction

Groundwater is a critical input to agricultural production across semi-arid regions, where precipitation alone is often insufficient to meet crop water demands. Over time, this reliance on groundwater for irrigation has enabled high levels of agricultural productivity in areas where rainfed production would otherwise be infeasible but also has contributed to declining aquifer levels in many regions. As concerns about long-term water availability grow, both policymakers and local stakeholders have increasingly turned to management strategies aimed at preserving groundwater resources, raising important questions about how policies that restrict water access are reflected in agricultural land markets.

1.1 Irrigation in Kansas

Kansas agriculture relies heavily on groundwater resources, particularly in the western portion of the state which resides on the High Plains Aquifer (HPA), to supply its extensive irrigated crop sector. The western portion of the state receives significantly less precipitation than the eastern and central portions (Figure A.1). Corn, the region's primary cash crop, requires 27 to 28 inches of water in its growing cycle. Corn's water requirements exceeds that of seasonal precipitation in western Kansas, making irrigation necessary to meet crop water demands (Araya et al. 2017). The state has nearly three million irrigated acres, and about 96% of all water used for irrigation is sourced from groundwater (Kenny and Juracek 2013). On average, around 15% of the cropland harvested in Kansas is irrigated, but irrigated cropland produces more than 30% of the total value of crops in the state (Rogers and Lamm 2012).

However, decades of groundwater withdrawals that exceed recharge have resulted in declining aquifer levels (Whittemore et al. 2018) and growing concern for the future of irrigated agriculture in Kansas.

Decades of intensive pumping since the popularization of irrigation have led to ‘cones of depression’[1] and a steady decline in saturated thickness across western Kansas (Butler Jr et al. 2013). In some areas, the depletion has been severe enough that high-capacity irrigation, or large-scale pumping systems that irrigate hundreds of gallons per minute to supply row crops, is no longer feasible (Steward et al. 2013; Donald O. Whittemore et al. 2023). In response, both state and local stakeholders have pursued legislative efforts to mandate groundwater reductions and prolong the aquifer’s lifespan. While the state has historically operated under a “first-in-time, first-in-right” doctrine, legislative efforts – by both local and state stakeholders – have been introduced to mandatorily reduce groundwater use to prolong the aquifer’s life. Mandatory reduction policies shift the traditional relationship between groundwater access and land value. Historically, secure water rights translated directly into more productive, and therefore more valuable, land (Edwards et al. 2025). Under mandatory reduction policies, however, the access-value relationship becomes more complex: landowners and markets must now weigh the cost of reduced water today against the long-term benefit of a more sustained aquifer in the future.

1.2 Literature Review

A substantial body of research has examined how groundwater contributes to agricultural land values by treating water access as a productive asset that is capitalized into land prices. The most commonly examined water access variables are depth to water—or the vertical distance

[1] A cone of depression forms when pumping from a well(s) lowers the water table beneath it, creating a bowl-shaped decline in the surface that radiates from the point of extraction (Theis 1938).

between the land surface and the water table—and saturated thickness, which indicates the volume of water stored in the aquifer (Mukherjee and Schwabe 2014; Sampson et al. 2019; Brozovic and Islam 2010; Ifft et al. 2018; Fenichel et al. 2016; Hornbeck and Keskin 2014; Torell et al. 1990). Depth to water and saturated thickness are primarily used in studies examining regions that are dependent on groundwater accessibility, like western Kansas, because depth and thickness affect irrigation feasibility. Several studies instead focus on water delivery volumes or permissible extraction, which are usually measured in acre feet per year (Crouter 1987; Faux and Perry 1999; Buck et al. 2014; Edwards et al. 2025). Delivery volumes and permissible extractions provide a more direct measure of available water, particularly in regions that use surface water. Region-specific variables also appear throughout literature, like saturated thickness or the vertical depth of water-bearing material (Sampson et al. 2019), water quality, particularly salinity concentration (Mukherjee and Schwabe 2014), and water restriction regulations (Ifft et al. 2018). Rather than reflecting disagreement over the correct empirical estimation and water variables, the variation in water measurement reflects how hydrogeologic conditions, water management frameworks, and data availability differ across regions and shape what is feasible and important to measure.

1.3 Research Objective

This study expands upon the hedonic land value literature by evaluating how groundwater access restriction policies in Kansas affect the value of irrigated cropland. Groundwater depletion is often characterized as a tragedy of the commons, where individual overuse leads to collective resource failure (Ostrom 1999). Market failure in groundwater use takes the form of negative externalities, because individual pumpers do not bear the full cost of aquifer depletion, and extraction rates exceed what would be socially optimal. In theory, regulation that transitions groundwater from an open-access resource to restricted use by curtailing extraction to socially optimal rates could secure long-run viability of the resource and increase the net present value (NPV) of irrigation returns, thus generating a premium on land sales (Plantinga and Miller 2001).

In application however, the net effect of groundwater restriction policies on land values, depends on competing factors. Restrictions impose immediate costs through reduced water allocations, potentially generating a land market discount, while also preserving long-term groundwater viability, potentially generating a land market premium. Whether land prices reflect a premium or discount depends on how the market values reduced current groundwater extraction compared to increased future groundwater availability and represents the empirical focus of this study.

Using a methodological approach consistent with prior hedonic analyses, this paper examines how regulatory limits on groundwater use are reflected in observed land prices. An advantage of this study is the use of transaction-level land sales data, which provide direct evidence of market valuations rather than relying on aggregated or appraisal-based measures. Transaction-level data allow for a more precise assessment of how changes in groundwater access are capitalized into land values in one of the most groundwater-dependent agricultural regions in the United States. Given the limited number of post-policy transactions within the Sheridan 6 Local Enhanced Management Area (LEMA), the regression analysis is supported with a matched transaction comparison approach that identifies similar transactions sold outside the policy boundary to provide additional evidence on the policy's potential impact on land values.

Chapter 2 - Background

Understanding how groundwater restriction policies affect agricultural land values requires context about both the legal framework governing water use in Kansas and the specific mechanisms in which the restrictions are implemented through. This section outlines the evolution of Kansas water law, the institutional structure of groundwater management districts, and the two policy areas examined in this study.

2.1 Water Law in Kansas

Prior to 1945, Kansas water law was defined by common law doctrines similar to states in the eastern United States, where the right to use water is tied to ownership of land adjacent to a water resource (e.g., riparian rights). Common law in groundwater contexts permits landowners to use water beneath their property without legal restriction (Peck 2013; Griggs 2014). However, the common law approach ultimately failed in Kansas due to the state's finite water resources and the advent of irrigation technologies such as the center pivot (Peck 2005). The inadequacy of the common law system was formally recognized by the Kansas Supreme Court in the 1944 case of *State ex rel. Peterson v. Kansas State Board of Agriculture*, which highlighted the Chief Engineer's lack of authority to regulate water use. The Peterson ruling was a direct catalyst for the legislative reform that redefined water rights in the state.

Responding to the failures of the common law doctrines, state legislation created the 1945 Kansas Water Appropriation Act (KWAA). The KWAA established the prior appropriation doctrine, or the principle of "first in time, first in right," meaning the individual who establishes a beneficial use of water first holds the senior priority right. (Rodgers et al. 2013). Prior appropriation shifted the legal status of water by declaring that all water within the state is dedicated for the use of the people (K.S.A. 82a-702). Landowners were able to retain the right to use water for beneficial purposes, but they no longer "owned" the water. The Division of Water Resources (DWR) allocates water rights, which are defined as both appurtenant to and severable from the land (K.S.A. 82a-701(g)). Appurtenant status means, by default, a water right is legally attached to the specific parcel of land where the water is used and typically transfers when the land is sold. However, since it is also severable, the owner can detach the water right from the original parcel and, with approval, transfer it to a different location or change type of use. The 1945 legislation allowed water rights to be treated as property, which provides water right holders with legal protections similar to those of land ownership.

2.2 Groundwater Management Districts & Restriction Mechanisms

The rapid expansion of irrigated agriculture across western Kansas accelerated the decline of the HPA through the late 1960s, prompting the Kansas legislature to enact updates that could address area-specific water management concerns across the state (Rodgers et al. 2013). Legislative concerns led to the passage of the Groundwater Management District (GMD) Act in 1972 (K.S.A. 82a-1020 et seq.). The GMD Act empowered local water users with the ability to determine the future of water management in their area while preserving existing state water use doctrines. GMDs are local administrative bodies governed by elected boards of water users and landowners. A significant part of the GMD framework allowed for "basin closures", or the formal closing of specific areas for new water right permits, subject to approval by the Chief Engineer of the DWR. Basin closures created a crucial link between state legislation and policies and allowed region-specific needs across the western portion of the state to be addressed.

To address increasingly critical groundwater declines, an amendment was added to the GMD Act in 1978, which introduced Intensive Groundwater Use Control Areas (IGUCAs). The IGUCA amendment allowed the Chief Engineer to provide input and solutions for groundwater concerns from the DWR through created provisions (K.S.A. 82a-1038). As a top-down administrative tool, an IGUCA grants the DWR the authority to curtail groundwater allocations, which has primarily been based on water right seniority (K.S.A. 82a-1038(b2)). In contrast, Local Enhanced Management Areas (LEMAs) were introduced in 2012 to act as a "bottom-up" approach. Unlike state-led IGUCAs, LEMAs allow GMDs to create goals and set measures to aid water conservation with the input of local stakeholders (K.S.A. 82a-1041), subject approval by DWR.

The present study focuses on two policy areas: the Walnut Creek IGUCA in central Kansas and the Sheridan 6 LEMA in northwest Kansas. The Walnut Creek IGUCA was initiated in 1992 by the Chief Engineer after the DWR concluded that groundwater withdrawal rates by local agricultural irrigators were affecting surface water flow to the Cheyene Bottoms Wildlife Area which resides in the Walnut Creek drainage basin (DWR 2009). The DWR also stated that the rate of withdrawals were collectively greater than that of recharge. Protecting the Cheyenne Bottoms was the primary focus of the IGUCA due to the Kansas Department of Wildlife & Parks holding a vested right[2] to the surface water in the Walnut Creek. The Sheridan 6 LEMA was initiated by GMD No.4 in 2012 with the goal of extending the life of the aquifer by reducing the rate of groundwater withdrawal (Golden 2018). Both policies provide five-year allocation curtailments for water right holders. However, the curtailment methods differ in meaningful ways. The Walnut Creek IGUCA curtailments were based on water right seniority, with junior rights[3] receiving larger curtailments than senior rights. By comparison, allocations within the

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[2] Vested rights in Kansas predate the 1945 KWAA and are recognized under common law doctrine. Unlike prior appropriation rights established under the KWAA, vested rights are constitutionally protected property interests.
[3] Junior rights were defined as having a priority date later than October 1, 1965.

Sheridan 6 LEMA were granted uniformly across irrigators. Both policies effectively decreased aggregate groundwater usage by around 20% of historical use.

Chapter 3 - Data

The study utilizes data from multiple sources. Table 1 shows the summary statistics for the variables used in the empirical analysis. The rest of Section 3 details each source of data.

3.1 Transaction-level Sales Data

This analysis utilizes transaction-level land data for every agricultural land transaction in

Table 1. Summary Statistics of Variables of Interest

Statistic	Mean	Median	St. Dev.	Min	Max
Real Price per Acre	2,423.25	1,987.83	1,609.77	149.86	8,774.85
Restriction Indicator (IGUCA)	0.07	0	0.26	0	1
Restriction Indicator (LEMA)	0.01	0	0.1	0	1
Restriction Indicator (Any)	0.08	0	0.27	0	1
Dryland Proportion	0.29	0.22	0.18	0	0.98
Irrigated Proportion	0.64	0.76	0.23	0.01	1
Grassland Proportion	0.07	0	0.15	0	0.91
Clay (%)	22.23	22.43	4.38	6.42	42.93
Silt (%)	58.9	64.37	13.89	9.16	68.69
Sand (%)	18.87	13.05	16.13	6.29	84.25
Soil Organic Carbon (kg/m^2) (0-100cm)	8.85	8.85	8.85	8.85	8.85
Slope (%)	2.19	1.41	1.78	0.02	9.78
5-yr Avg Precipitation	19.29	19.64	3.26	7.52	27.22
5-yr Avg Degree Days (10–32C) / 100	169.94	170.11	19.94	134.08	216.11
5-yr Avg Degree Days (>32C)	51.42	50.26	23.13	16.29	161.67

Note: N = 523

Kansas that is greater than 40 acres in size from 1988 to 2024 obtained from Property Valuation Division (PVD) of the Kansas Department of Revenue. The analysis is restricted to transactions within counties surrounding the Walnut Creek IGUCA and the Sheridan 6 LEMA that contain irrigated acres. The counties included are Ness, Rush, and Barton surrounding the Walnut Creek IGUCA and Thomas and Sheridan surrounding the Sheridan 6 LEMA. Transactions are dropped if they have total acreage greater than 5,000 acres or have total appraised values of improvements greater than $100,000. Transactions are also restricted to arms-length to ensure accurate reflections of fair market values. These restrictions leave 515 observable transactions, including 5 sales within the Sheridan 6 LEMA after the policy enactment and 38 sales within the Walnut Creek IGUCA after the policy enactment. Transaction values are converted to 2024 values using the consumer price index.

3.2 Soil Characteristics

Soil characteristic data was obtained from the Soil Survey Geographic Database (SSURGO) soil survey on the website of the USDA Natural Resource Conservation Service (NRCS). The PVD data contains information on the acres of the parcel represented by each soil type. The soil types are then linked to the SSURGO data which provides information on the characteristics of each soil type, which is then aggregated across to the parcel level. The soil variables include percentages of clay, silt, and sand composition, the organic matter content in the soil, and the slope or elevation. These attributes provide a comprehensive view of soil texture, fertility, and topographical constraints, all of which can affect the productivity and usability of agricultural land.

3.3 Climate Data

Climate data is obtained from the PRISM Group, which is a part of the Northwest Alliance for Computational Science and Engineering. Weather data is a five-year moving average within the growing season (April to September) up to the year of the transaction and is averaged at the county level.

Chapter 4 - Methodology

This section outlines the empirical approach used to evaluate how groundwater restriction policies are capitalized into irrigated cropland values. The primary estimation strategy is a hedonic regression that estimates the capitalization effects of the Walnut Creek IGUCA and the Sheridan 6 LEMA while controlling for soil, land, and climate characteristics. Descriptive statistics and mean comparison tests are first presented to characterize the differences between the transactions inside and outside the two policy areas, and a matched-parcel comparison is conducted as a supplementary case-study approach to provide additional evidence on the Sheridan 6 LEMA's effect on land value.

4.1 Descriptive Statistics

Tables 2 and 3 show the descriptive statistics and mean comparison tests for transactions located inside, post policy enactment, and outside the water restriction policies for the Sheridan 6 LEMA and the Walnut Creek IGUCA, respectively. The comparisons provide insight into how transactions within the curtailment areas differ from the control transactions in terms of the variables of importance.

Table 2. Descriptive Statistics and Mean Differences for Sheridan 6 LEMA Transactions

Variable	Mean Inside	SD Inside	Mean Outside	SD Outside	Mean Diff	95% CI Low	95% CI High	Sig
Real Price per Acre	5,078.7	1,312.8	2,397.6	1,591.9	2,681.1	1,057.4	4,304.9	* *
Dryland Proportion	0.31	0.18	0.29	0.18	0.02	-0.2	0.24	
Irrigated Proportion	0.66	0.18	0.64	0.23	0.02	-0.2	0.24	
Grassland Proportion	0.03	0.05	0.07	0.15	-0.04	-0.1	0.02	
Clay (%)	23.13	0.1	22.22	4.41	0.91	0.52	1.3	* * *
Silt (%)	58.26	2.8	58.91	13.96	-0.65	-4.04	2.75	
Sand (%)	18.61	2.85	18.87	16.21	-0.26	-3.74	3.21	
Soil Organic Carbon (kg/m^2) (0–100 cm)	9.49	1.27	8.84	3.04	0.65	-0.9	2.21	
Slope (%)	2.36	0.48	2.19	1.79	0.17	-0.41	0.75	
5-yr Avg Precipitation	13.81	4.61	19.35	3.2	-5.54	-11.25	0.17	
5-yr Avg Degree Days (10–32C) / 100	176.27	4.88	169.88	20.02	6.39	0.48	12.31	*
5-yr Avg Degree Days (>32C)	44.99	9.39	51.48	23.22	-6.49	-17.99	5.01	
Sale Year	2021.8	1.3	2002.9	10.1	18.9	17.3	20.52	***

Note: N = 523 (Inside = 5, Outside = 518). *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

4.1.1 Sheridan 6 LEMA

Transactions sold within the Sheridan 6 LEMA post policy enactment (N = 5), sold at a significantly higher amount relative to the control transactions (N = 518), with a mean real price per acre of $5,078.73 compared to $2,397.62. This result alone does not prove that transactions sold at different values solely because of being within the policy area, as the comparison does not control for other factors that may influence land value. Land composition variables in Sheridan 6 LEMA show no significant differences to those of control transactions; with similar proportions of dryland (31% vs. 29%), irrigated land (66% vs. 64%), and grassland (3% vs. 7%).

Table 3. Descriptive Statistics and Mean Differences for Walnut Creek IGUCA Transactions

Variable	Mean Inside	SD Inside	Mean Outside	SD Outside	Mean Diff	95% CI Low	95% CI High	Sig
Real Price per Acre	1,881	1,328.3	2,465.7	1,623.3	-584.7	-1,043	-126.33	*
Dryland Proportion	0.3	0.2	0.29	0.18	0.01	-0.06	0.07	
Irrigated Proportion	0.55	0.23	0.64	0.23	-0.1	-0.18	-0.02	*
Grassland Proportion	0.16	0.16	0.06	0.15	0.09	0.04	0.14	**
Clay (%)	27.09	4.29	21.84	4.16	5.25	3.79	6.7	***
Silt (%)	62.59	4.56	58.61	14.34	3.98	2.02	5.94	***
Sand (%)	10.32	4.14	19.55	16.53	-9.23	-11.22	-7.23	***
Soil Organic Carbon (kg/m^2) (0–100 cm)	14.23	3.01	8.42	2.59	5.81	4.8	6.83	***
Slope (%)	1.35	0.68	2.26	1.83	-0.91	-1.19	-0.64	***
5-yr Avg Precipitation	22.77	2.59	19.02	3.15	3.75	2.85	4.64	***
5-yr Avg Degree Days (10–32C) / 100	192.85	9.79	168.15	19.41	24.7	21.07	28.33	***
5-yr Avg Degree Days (>32C)	74.08	23.25	49.64	22.19	24.43	16.56	32.31	***
Sale Year	2004.5	9.8	2003	10.3	1.5	-1.8	4.89	

Note: N = 523 (Inside = 38, Outside = 485). *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

The soil characteristic variables are largely similar between the Sheridan 6 LEMA and control transactions. The only significant difference is in clay content, 23.13% compared to 22.22%, though the magnitude of the difference is relatively small at less than one percentage

point, it has a p-value of less than 0.001. Other soil composition characteristics however are not significantly different, with silt composition (58.26% vs. 58.91%) sand composition (18.61% vs. 18.87%), soil organic carbon (9.49 vs. 8.84 kg/m^2), and slope (2.36% vs. 2.19%) This indicates that the soil characteristics within the Sheridan 6 LEMA transactions are similar to the control transactions.

There were differences in climate variables between the Sheridan 6 LEMA transactions and the control transactions; however, these differences should be interpreted with caution. The

Sheridan 6 LEMA transactions sold on average in 2022 whereas the control transactions sold on average in 2003, a statistically significant difference of nearly 19 years. It is important to note that land values in Kansas have been increasing over time in real terms. Additionally, since the climate variables are five-year moving averages prior to the sale year, observed differences may reflect temporal variation in climate across the sample period rather than true spatial differences.

4.1.2 Walnut Creek IGUCA

Transactions within the Walnut Creek IGUCA post-policy enactment (N = 38), sold at a statistically significant discount relative to the control transactions, with a mean real price per acre of $1,881.03 compared to $2,465.73. While this difference is statistically significant at the 5% level, this is a simple price difference and not necessarily attributable to the effect of the policy. IGUCA transactions have a significantly lower proportion of irrigated land (55% vs. 64%) and higher grassland proportion (16% vs. 6%), suggesting less water intensive agricultural production within the policy area compared to that of the control transactions. Dryland proportion shows no significant difference (30% vs. 29%).

Soil characteristics differ substantially between IGUCA transactions and control transactions. Transactions inside the IGUCA have higher clay content (27.09% vs. 21.84%), higher silt content (62.59% vs. 58.61%), and lower sand content (10.32% vs. 19.55%), with the differences all being statistically significant at the 0.1% level or better. IGUCA transactions also have significantly higher soil organic carbon content (14.23 vs. 8.42 kg/m^2) and lower average slope (1.35% vs. 2.26%), also both statistically significant at the less than 0.1% level.

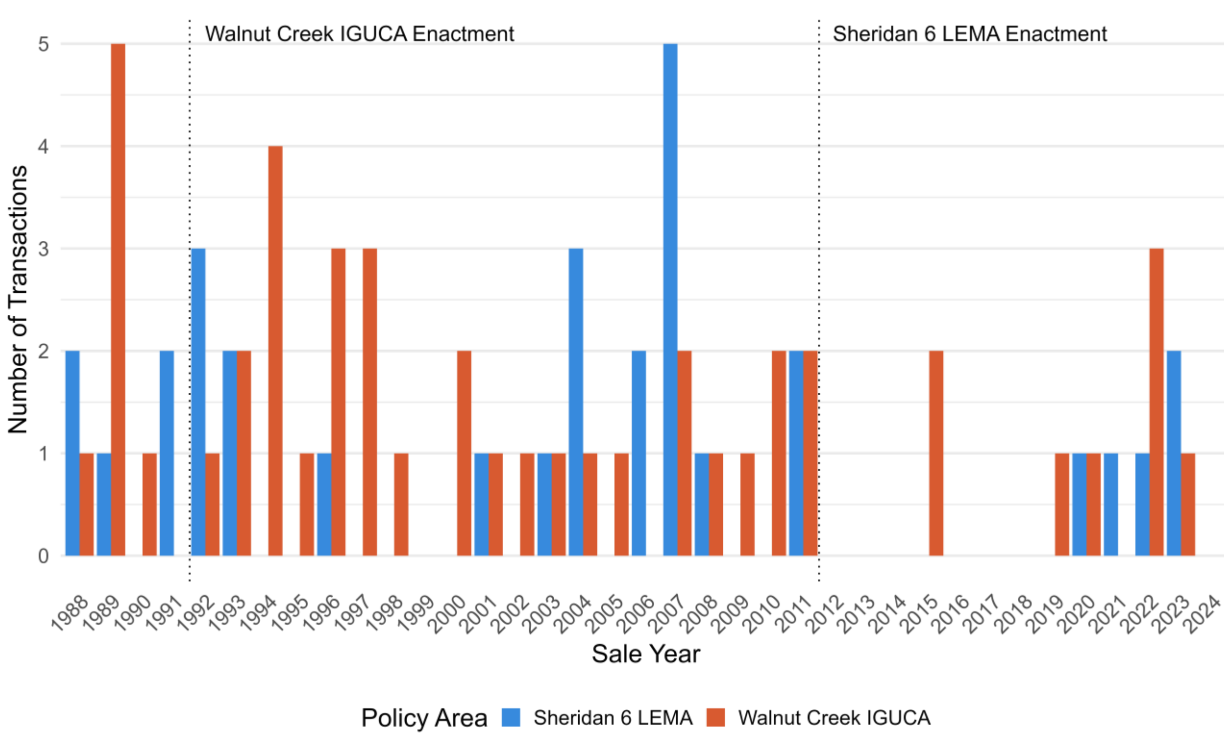
Climate condition variables highlight further the stark contrast in temperature and precipitation between transactions inside and outside the IGUCA. Unlike the LEMA sample, sale years between IGUCA and control transactions are statistically similar, averaging 2005 and

2003, respectively. Similarity in sales years suggest the observed climate differences reflect spatial variation rather than temporal. Transactions within the IGUCA experience significantly higher five-year average precipitation (22.77 vs. 19.02 inches), more five-year average growing degree days between 10–32°C (19,285 vs. 16,815), and more extreme heat degree days above 32°C (74.08 vs. 49.64), all statistically significant at the 0.1% level. The climate differences suggest that the IGUCA region has a wetter and warmer growing climate compared to that of control transactions.

4.2 Transaction Timing and Anticipatory Market Behavior

To examine whether transactions had occurred prior to the policy enactment dates, in both the Sheridan 6 LEMA and the Walnut Creek IGUCA, a bar chart is created illustrating the number of transactions sold within each policy area across the observation period (Figure 1). Examining the pre-policy transaction pattern for the Walnut Creek IGUCA shows a notable

Figure 1. Bar Plot of Number of Transactions across Sale Years within Policy Areas



spike of five transactions in 1989, three years prior to the enactment of the IGUCA Order. While this is before the formal initiation of the IGUCA proceedings in March 1990, there had already been request submissions prior by the Kansas Department of Wildlife and Parks and Big Bend GMD No. 5 to the Chief Engineer (DWR 1990). Transaction volume then fell to one per year in 1990 and 1991 as formal hearings proceeded, which may reflect reduced market activity once sellers who anticipated the restriction had already transacted.

For the Sheridan 6 LEMA, enacted in 2012, the pre-policy year of 2011 recorded two transactions. The LEMA process under K.S.A. 82a-1041 required GMD No. 4 to develop a formal proposal and hold public meetings with local water users prior to the official submission to the Chief Engineer which occurred in March 2012. This means there had been awareness of the potential restriction policy among local landowners likely predating the formal enactment. However, two transactions in a single pre-enactment year is consistent with the low baseline turnover rate observed throughout the broader sample and does not constitute meaningful evidence of anticipatory selling behavior.

To assess whether any anticipatory transactions meaningfully influence the regression estimates, a robustness check is conducted in which the policy treatment indicator is shifted two years earlier than the actual enactment date for each policy area. If anticipatory selling is concentrated among sellers expecting a price discount, the treatment coefficient estimated under the shifted time window would be expected to change the sign relative to the baseline model. Results of this robustness check are discussed in Section 5.2.

4.3 Matched-Transaction Comparison

Unlike the Walnut Creek IGUCA, which has 38 post-policy transactions, the Sheridan 6 LEMA only has five, limiting the statistical power of the hedonic regression to detect the policy's effect with precision. To complement the regression analysis and provide additional evidence for the LEMA policy, a matched parcel comparison is conducted.

This case-study approach identifies transactions sold within the Sheridan 6 LEMA and then finds a comparison set of "like" transactions sold outside the policy boundary but within similar market, soil, and aquifer conditions. For each Sheridan 6 LEMA transaction, comparable transactions are identified using the following matching criteria. First, geographic proximity: the transaction must be either located 10 miles of the Sheridan 6 LEMA policy boundary or within GMD 4. Second, land use similarity: irrigated proportion of total acreage within a transaction must be within +/- 0.05 (5 percentage points). Third, soil composition: the transaction must have clay, silt, and sand percentages each within +/- 7.5 percentage points. Finally, timing: the transaction must have occurred within +/- 3 years of the LEMA transaction.

Matching criteria ensure that matched transactions are comparable in land use composition, aquifer and market conditions, and soil productivity, while differing primarily in their exposure to the groundwater restriction policy. By comparing real price per acre of transactions within the Sheridan 6 LEMA to matched counterparts, this matched-transaction approach provides a direct way to assess how restriction policies are capitalized into land values. The matched comparison offers interpretable, transaction-specific evidence that complements the broader regression framework.

4.4 Hedonic Model Estimation

Land values are modeled using a hedonic pricing framework. The conceptual basis of the hedonic model is that the i^{th} parcel can be expressed as a function of its characteristics z_i (Rosen 1974). The fundamental asset market equation states that in a competitive land market, the agricultural land value will reflect the present discounted value of the stream of current and future rents (Plantinga and Miller 2001).

The hedonic price function incorporates three categories of parcel attributes: water restriction policy exposure z^r, land and soil characteristics z^s, and climate variables z^c. These attributes collectively are a vector of characteristics z_i, that determines the observed market price for parcel i, as shown in expression (1):

$$P(z_i) = P(z^r, z^s, z^c) \tag{1}$$

To estimate the contribution of each component of the vector z_i to land value, a semi-log functional form is specified, allowing coefficient estimates to be interpreted as the proportional change in price per-acre resulting from marginal changes in each component. The model estimated is (2):

$$\ln\left(\frac{Price}{Acre}\right)_{it} = \beta_r z_{it}^r + \Gamma_s{}'Z_{it}^s + \Gamma_c{}'Z_{it}^c + \delta_t + \varepsilon_{it} \tag{2}$$

Where the dependent variable, $\ln(\text{Price/Acre})_i$ is the natural logarithm of the observed sale price per acre for transaction i. The parameter, β_r, is a coefficient, or pair of coefficients in the case of model 2, which estimates the Walnut Creek IGUCA and Sheridan 6 LEMA effects separately, reflecting the total effect of groundwater restriction policy exposure on land value. The terms Γ_s, and Γ_c are coefficient vectors to be estimated. The term δ is included to capture linear trends in land values over the sample period not attributed to the variables.[4] The error term, ε_{it} captures unobserved heterogeneity and measurement error.

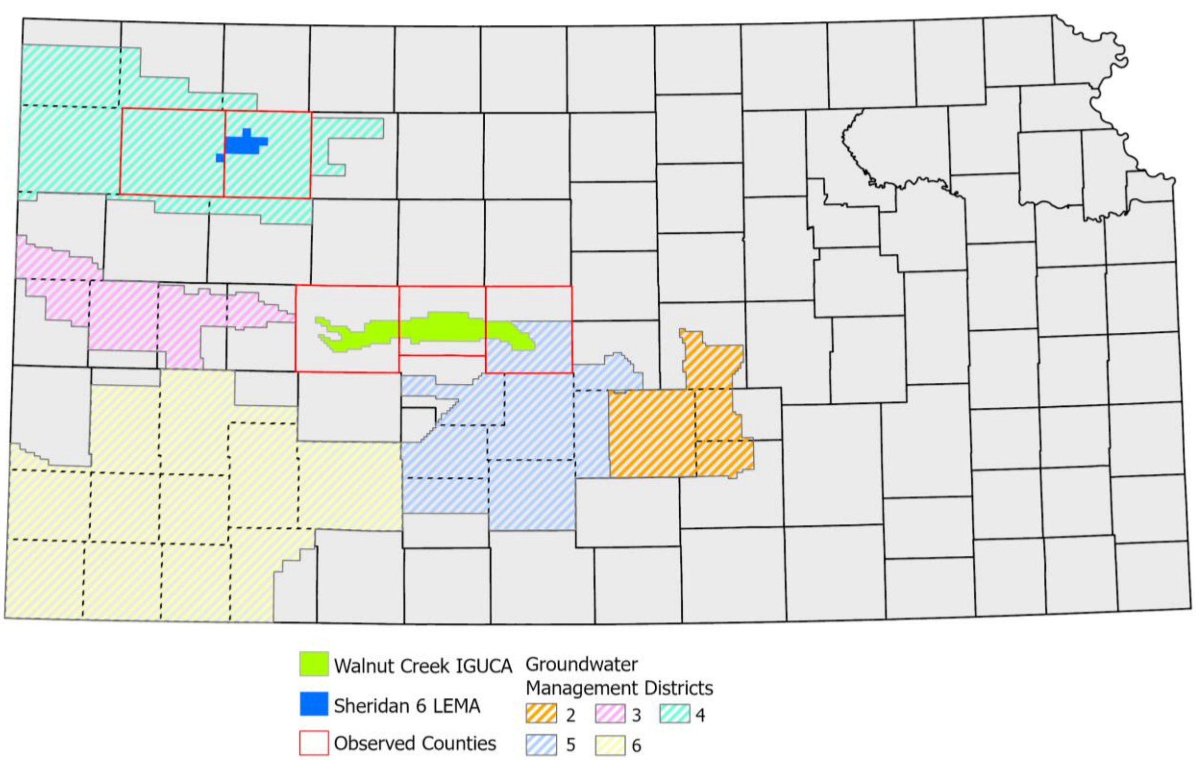
Four models are estimated using alternative water restriction definitions and geographic scopes. Model 1 includes a single indicator equal to one if the transaction is located within either

[4] Models were also estimated substituting year fixed effects for the continuous year trend as a robustness check.

the Sheridan 6 LEMA or the Walnut Creek IGUCA. Model 2 separates the policy treatment into two indicators, one for each water management area. The control observations in Models 1 and 2 consist of irrigated transactions located in the counties surrounding the water restriction policy but outside the policy areas boundaries. Control transactions serve as the counterfactual, representing expected land value in the absence of groundwater use restrictions.

Models 3 and 4 restrict the sample geographically: Model 3 includes only transactions in Thomas and Sheridan counties (i.e., in the vicinity of the LEMA), while Model 4 includes only transactions within Barton, Rush, and Ness counties (i.e., the vicinity of the IGUCA). The four-model structure allows for the estimation of both pooled and region-specific effects of groundwater regulation. Figure 2 provides a map of the study area, illustrating where the water policy regions are and the counties used as controls.

Figure 2. Map of Study Area



4.5 Alternative Estimation Strategies & Power Analysis

A difference-in-differences (DiD) framework was considered for the analysis as it provides a natural design for evaluating the causal effect of policy change by comparing before and after policy enactment observations between restricted and unrestricted areas (Card and Krueger 1994; Earnhart and Hendricks 2023). However, in the present study, the temporal distribution of available transaction data makes a robust DiD estimation for both policy areas infeasible.

The Walnut Creek IGUCA was enacted in 1992, four years after the start of the transaction dataset, resulting in only seven observed transactions before policy. The limited pre-policy baseline provides insufficient observations to establish reliable parallel trend tests. In the Sheridan 6 LEMA, the data constraint is the opposite. The Sheridan 6 LEMA was enacted in 2012, and due to the slow turnover in irrigated agricultural land and the small policy area, there are only five observable transactions post-policy through 2024. The scarcity of pre- and post-treatment observations for the Walnut Creek IGUCA and Sheridan 6 LEMA, respectively, undermines the precision and statistical power required for DiD estimation.

To assess the reliability of the main regression model, Model 2, and evaluate the risk of Type I and Type II errors, simulation-based power analyses were conducted. First, 1,000 data sets were simulated under the null hypothesis, (true effect = 0), while preserving model structure, covariates, and residuals. For each simulated dataset, Model 2 was re-estimated, and the analysis recorded whether the coefficients for the treatment variables were statistically significant, (α = 0.05). The proportion of false-positives across simulations indicates whether the model produces appropriately calibrated p-values or exhibits Type I error rates.

Second, another 1,000 data sets were simulated with true effects equal to the observed coefficients in Model 2. The second simulation estimates the probability of detecting effects of the observed magnitude given the limited sample size and model specification. Together, the two simulations provide evidence on the reliability and limitations of the hedonic regression models results, which are needed due to the limited number of treated transactions.

Chapter 5 - Results

This section presents the empirical findings in three parts. The matched-transaction comparisons are discussed first, providing transaction-specific evidence on the Sheridan 6 LEMA. The hedonic regression results are presented next across the four model specifications. Lastly, the power analysis results are discussed to contextualize the precision and limitations of the regression estimates given the available sample sizes.

5.1 *Matched-Transaction Comparisons*

Table 4 presents the characteristics of each Sheridan 6 LEMA transaction alongside summary statistics of their matched comparison transactions. The transaction number was assigned arbitrarily and serves only as an identification rather than a ranking. The matching process identified between 2 and 10 comparable transactions for each LEMA transaction, given the criteria outlined in section 4.2. Notably, Transactions 3,4, and 5 share overlapping sets of matched transactions due to their similar parcel characteristics and time of sale.

Transaction 1 presented the least number of matched transactions given the criteria. This transaction occurred in April 2020 and consisted of a single parcel of 155.1 acres. The composition of land usage was 88.4 acres of irrigated cropland (57% of total acreage), and 66.7 acres of dryland (43% of total acreage). The main reason for the small number of matched transactions in the matching criteria was the +/- 5% of irrigated cropland within the transaction.

Table 4. Matched-Transaction Comparison for Sheridan 6 LEMA Transactions

Transaction*	Sale Date	LEMA Real Price ($/acre)	% Irrigated	% Inside of LEMA	Transactions Matched	Avg Matched Real Price ($/Acre)	Price Difference	% Difference
1	Apr-20	4914	57	100	2	5207.059	-293.059	-5.96%
2	Jun-21	3293	38	100	3	3060.987	232.0133	7.05%
3	Mar-23	6957	77	100	5	5609.139	1347.861	19.37%
4	Sep-23	5398	75	100	5	5609.139	-211.139	-3.91%
5	Mar-22	4832	80	50	10	5566.754	-734.754	-15.21%

Note: Matched transaction identified using four criteria: geographic proximity (within 10 miles of Sheridan 6 LEMA boundary or within GMD 4), irrigated proportion (±5%), soil composition (clay, silt, sand ±7.5% each), and temporal proximity (±3 years of sale date). One matched transaction was excluded due to its direct proximity to the town of Hoxie, which could introduce non-agricultural valuation effects and raise its price above standard market price

Given the irrigated cropland percent was 57%, it was lower and out of the 5% bounds than that of the average of 65% of transactions sold in the location and date criteria. This lower irrigation intensity meant fewer comparable transactions met the land use similar criteria. The two matched transactions averaged $5,207 per acre compared to the $4,914 per acre for the LEMA transaction – roughly a 6% discount.

Transaction 2 occurred in June 2021, was comprised of 311.7 acres across two parcels, and had the lowest irrigated proportion among all the LEMA transactions. The specific land types were 118.4 acres of irrigated cropland (38% of total acreage), 177.7 acres of dryland (57%), and 15.6 acres of grassland (5%). This transaction also included $18,000 in total appraised improvements, which slightly complicate direct price comparisons. Despite the relatively low irrigation intensity, the matching process identified three comparable transactions with similar characteristics. These LEMA transactions sold for $3,293 per acre compared to an average of $3,061 per acre among the matched transactions, representing a 7.1% premium. This premium, however, could be the total value of improvements capitalized in the price per acre, as none of the matched transactions possessed improvements, suggesting that 7.1% land value premium may be overestimated.

Transaction 3 occurred in March 2023, consisted of 312 acres with an above average irrigated proportion among LEMA transactions: 240.2 acres of irrigated cropland (77% of total acreage) and 71.8 acres of dryland (23%). This transaction had five comparable transactions satisfying the given criteria. This LEMA parcel sold for $6,957 per acre compared to an average of $5,609 per acre among the matched transactions. This represents a substantial 19.4% premium, which is the largest positive price differential in the sample, suggesting either strong demand and buyer valuations of this land or transaction-specific attributes that are not captured by the matching criteria.

Transaction 4 occurred in September 2023, comprised 157.4 acres with 118.1 acres of irrigated cropland (75% of total acreage), 20.5 acres of dryland (13%), and 15.7 acres of grassland (10%). This similar land use composition of that of Transaction 3 and similar sale date, resulted in this transaction being compared to the same five transactions that Transaction 3 were matched to. Despite being matched to the same transactions, Transaction 4 was sold for $5,398 per acre, $211 per acre less than the average of the matched transactions. The contrasting price patterns between Transactions 3 and 4, a 19.4% premium versus a 3.9% discount, despite sharing similar comparison transactions highlights the complexity of transaction-specific factors that are not observed within the dataset. This could include idiosyncrasies in individual buyer valuations, competition amongst buyers, financing terms, or unobserved parcel quality.

Transaction 5, sold in March 2022, consisted of two parcels with a combined 312.6 acres with 249.4 acres of irrigated cropland (80% of total acreage) and 63.2 acres of dryland (20%). This transaction represents a unique case, where one parcel is completely within the Sheridan 6 LEMA and the other parcel is not, resulting in 50% of total acreage being within the policy area. Due to these parcels' large irrigation percentage of total acreage, there are ten matched transactions identified. This LEMA transaction sold for $4,832 per acre compared to an average of $5,567 per acre among matched transactions, representing a 15.2% discount. The substantial discount is notable given the transaction's productive characteristics. However, a case-study comparison is made difficult due to this transaction's acreage being split inside and outside the Sheridan 6 LEMA.

5.2 Regression Results

Table 5. Regression Results from Main Specifications

	Model 1 Single Dummy	Model 2 Two Dummy	Model 3 LEMA Only	Model 4 IGUCA Only
Intercept	-82.0*** (4.03)	-81.3*** (4.03)	-88.6*** (5.87)	-74.2*** (6.85)
Any Policy	-0.126 (0.086)	—	—	—
Sheridan 6 LEMA	—	0.205 (0.199)	0.179 (0.203)	—
Walnut Creek IGUCA	—	-0.206** (0.096)	—	-0.107 (0.102)
Dryland Proportion	0.476** (0.180)	0.445** (0.180)	0.320 (0.236)	0.340 (0.335)
Irrigated Proportion	1.44*** (0.151)	1.42*** (0.151)	1.49*** (0.191)	1.04*** (0.318)
Clay (%)	0.005 (0.006)	0.004 (0.006)	-0.003 (0.018)	0.016** (0.008)
Silt (%)	-0.003 (0.003)	-0.002 (0.003)	0.007 (0.009)	-0.01** (0.004)
Soil Organic Carbon	-0.005 (0.009)	-0.004 (0.009)	0.002 (0.011)	0.004 (0.016)
Slope	-0.041** (0.014)	-0.043** (0.014)	-0.021 (0.019)	-0.064 (0.043)
Precipitation	0.013* (0.007)	0.017** (0.007)	0.022** (0.011)	0.005 (0.021)
Moderate Days	-0.006** (0.003)	−0.006** (0.003)	-0.002 (0.004)	-0.028 (0.081)
Extreme Days	0.002 (0.002)	0.003 (0.002)	-0.001 (0.003)	0.003 (0.002)
Year	0.045*** (0.002)	0.044*** (0.002)	0.047*** (0.003)	0.041*** (0.004)
Observations	515	515	387	128
R2	0.62186	0.62442	0.62346	0.68818

Significance Codes: *p < 0.10, **p < 0.05, ***p < 0.01

The regression results for the four models are shown in Table 5. Across all models, the regression results indicate a strong overall fit, with r-squared values ranging from 0.62 to 0.69, suggesting that the included land use, soil, topography, time trend, and climate variables explain around 65 percent of variation in log land values. Proportion of irrigated land consistently exhibits a strong positive statistically significant coefficient, which is consistent with prior findings that access to irrigation is a major driver in agriculture land values (Sampson et al. 2019; Edwards et al. 2025). Dryland share also exhibits the expected sign and magnitude, indicating it goes for a premium compared to grassland (the reference land use type). The slope and precipitation coefficients are also observed to have the expected signs, aligning with what prior literature on value of these characteristics on land value (Mukherjee and Schwabe 2014; Sampson et al. 2019). The soil characteristic coefficients exhibit mixed results in terms of significance across the four models, which is consistent with studies which indicate that soil composition and quality influences land value in specific contexts but not always (Meissner and Musshoff 2022; Tavares et al. 2022). Overall, the control variables largely agree with prior hedonic land value studies across the models and provide support for the validity of the model specification.

The intercepts across the four model specifications are negative, ranging from -74.2 in Model 4 to -88.6 in Model 3, with all statistically significant at the 0.1% level. While a negative intercept is counterintuitive, it is likely due to the inclusion of the continuous year trend variable (which is positive and statistically significant). As a robustness check, the models were re-estimated substituting year fixed effects for the continuous year trend, which produced positive intercepts across all four models (see results in Table A.1). It is worth noting the estimated treatment effects exhibited similar signs and magnitudes across most specifications. However, statistical significance is lost in the Walnut Creek IGUCA treatment coefficient when year effects are specified, indicating unexpected year-to-year variation absorbs some of the IGUCA treatment effect.

The coefficient of the aggregated policy treatment dummy is -0.126 but is not statistically significant. This could indicate that on average transactions within policy areas have lower price per acres values, but the model estimate is imprecise. The Sheridan 6 LEMA coefficient was 0.205 in Model 2 and 0.179 in Model 3. Both coefficients are not statistically significant, but the similar magnitude and direction should be noted. The Walnut Creek IGUCA coefficient in Model 2 is -0.206 and statistically significant at the 5% level, indicating that transactions within the IGUCA tend to have on average an 18-19% lower price per acre compared to non-IGUCA transactions. In Model 4, the coefficient decreases in magnitude to -0.107 and loses statistical significance. The loss of statistical significance in Model 4 is likely explained by the smaller sample size.

The anticipatory sales robustness check, in which the policy treatment indicator is shifted two years prior to each policy's enactment date, produces results similar to the baseline specification (Table A.2 in the appendix). The Walnut Creek IGUCA coefficient is -0.195 and retains statistical significance at the 5% level, compared to -0.206 in the baseline Model 2, suggesting the baseline result is not sensitive to anticipatory transactions. The Sheridan 6 LEMA coefficient under the anticipatory window is 0.308 and marginally significant at the 10% level, though this result should be interpreted with caution given the very limited number of treated observations under either specification.

5.3 Power Analysis Results

The results of the simulation power analyses that were conducted are in Table 6. The Type I error calibration test showed that Model 2 produces appropriately calibrated inference, with observed false positive rates of 5.1% and 3.9% for the Sheridan 6 LEMA and Walnut Creek IGUCA respectively within the simulations ran. These levels close to the nominal significance rate of 5% indicate that the statistical inference is neither over nor underestimated.

Table 6. Simulation-Based Power Analyses for Model 2

Variable	Observed Coefficient	Type I Error Rate	Statistical Power
Sheridan 6 LEMA	0.205	5.1%	16.8%
Walnut Creek IGUCA	-0.206	3.9%	59.2%

The statistical power analysis, however, revealed the limitations in detecting observed effects in the model, primarily due to the low number of observations treated. For the Walnut Creek IGUCA, which had a statistically significant negative coefficient of -0.206 in Model 2, the estimated statistical power was 59.2%. A power of 59.2% means that if the Walnut Creek IGUCA truly discounts irrigated cropland values by the estimated 20.6%, a study of the same design would detect a statistically significant effect only about 59 times out of 100 replications, resulting in a 40.8% chance of a Type II error, or failing to detect a real effect. Conventional practice treats 80% as the minimum acceptable threshold. For the Sheridan 6 LEMA, the coefficient of 0.205 was not statistically significant and had an estimated power of 16.8%. In short, the low treatment observation counts leave the models underpowered to reliably distinguish real capitalization effects from sampling noise, and null or insignificant results should be interpreted with that limitation in mind.

Chapter 6 - Discussion

The results of this study provide mixed evidence that land values in Kansas are impacted by different water restriction policies. Estimated effects are consistently negative within the Walnut Creek IGUCA, suggesting a land value discount, while estimated effects are consistently positive within the Sheridan 6 LEMA, suggesting a land value premium. However, neither result is statistically conclusive. Taken together, these patterns suggest that groundwater policies may generate heterogeneous land value impacts that depend on regulatory design, the motivation of the restriction, and stakeholder involvement.

The negative capitalized effect observed in the Walnut Creek IGUCA is consistent with expectations for a top-down restriction not motivated by long-run irrigation viability. The IGUCA was enacted to protect the Cheyenne Bottoms, a state wildlife refuge rather than to sustain the aquifer for agricultural use, and producers had no input on its design and implementation. This distinction matters, as buyers may anticipate that the restriction reduces current cash returns without offering the long-run irrigation stability that would offset those losses, resulting in a price discount.

The statistically significant effect in the full sample estimation reflects buyers' expectations of lower future cash returns from land if it is within the IGUCA. The power analysis indicates this effect was detected with 59.2% power, while this is below the conventional 80% threshold, it strengthens the confidence that the negative effect is real but highlights the magnitude may be imprecise. When the geographic sample is narrowed in Model 4, the loss of statistical significance suggests that the contrast between IGUCA transactions and surrounding transactions becomes less pronounced. This could be due to similar cropping potential leading to similar future cash returns from land, or more simply the model loses power as the sample size shrinks. This result further emphasizes the importance of not only the local context but also the reasons why a policy is enacted in measuring the value of groundwater policies.

In contrast, the Sheridan 6 LEMA did not have any measurable price effects, though power analysis reveals this null result is inconclusive. With only 16.8% statistical power to detect an effect of the observed magnitude, the lack of observations leads to an inability to distinguish between a true null effect and a real effect that went undetected. The anticipatory sales robustness check, which shifts the treatment window two years prior to enactment, produces a marginally significant positive coefficient of 0.308, suggesting that buyers transacting during the period when GMD No. 4 was actively developing the LEMA proposal with local water users may have viewed the pending restriction favorably. This is consistent with the interpretation that locally engaged buyers anticipated the policy would extend aquifer life and preserve long-run irrigation returns, though this result should be interpreted cautiously given that only two pre-enactment transactions drive the estimate change. The matched-transaction comparisons provides additional context for interpreting these imprecise regression results. The transaction-level comparables analysis revealed substantial heterogeneity in price outcomes across the five Sheridan 6 LEMA transactions, where individual price differences ranged from a 19.4% premium in Transaction 3 to a 15.2% discount in Transaction 5 relative to their average matched transactions. Two transactions sold at a premium relative to their matched transactions while three transactions sold at a discount relative to their matched transactions, yielding no consistent pattern of direction to be observed. The transaction comparables findings support the conclusion that the LEMA's effect on land values, is not systematically positive or negative.

With these results there are several possible interpretations. First, this could simply imply that this water policy does not result in any discounts or premiums on land values. Since the LEMA is locally driven and primarily designed to prolong the usable life of the Ogallala Aquifer, buyers may view the reductions in water allocation as being offset by the long-run potential economic benefits of extending irrigation viability in the region. The transaction comparables analysis provides support for this interpretation, where small premiums and discounts for LEMA transactions are reflective of normal market variation. A second explanation for these results is the lack of post-policy transactions which reduce statistical power and make it difficult to detect even moderate effects. Furthermore, the LEMA policy framework could be viewed as more flexible and less rigid than that of the IGUCA due to local producers being involved in the design process. Ultimately, the lack of post-policy transactions severely limits the statistical power of the analysis, making it difficult to place substantial confidence in the measured LEMA coefficients. Overall, these findings reveal a consistent directional pattern: estimated land value effects are negative within the Walnut Creek IGUCA and positive within the Sheridan 6 LEMA across model specifications. However, neither effect is statistically conclusive. Infrequent irrigated land transactions within these small geographic policy areas severely limit statistical power, making it difficult to detect and precisely estimate any capitalization effect. This consistently in sign nonetheless suggests that market participants may weigh the costs of top-down restrictions differently than the long-run stability that locally designed regulations offer. As concerns about the future of irrigated agriculture grow, understanding how land markets respond to different regulatory approaches remains an important area for future research as longer post-policy observations windows and larger transaction samples become available.

Essay 2 – Landowner Perspectives & Land Value Impacts of Woody Encroachment

Chapter 1 - Introduction

Across much of the Great Plains grasslands, woody plant species are expanding and dominating regions that were once primarily herbaceous vegetation. This ecological shift from grassland into woodland, known as woody encroachment, has reshaped rangeland ecosystems and generated concerns from landowners, conservationists, agricultural producers, and policymakers (Morton et al. 2010). For these agriculturally dependent regions, expansion of tree and shrub species may carry significant economic implications.

Prior studies have documented the ecological causes and consequences of woody encroachment (Soubry and Guo 2022), but little research has been dedicated to the economic implications of woody vegetation on the agricultural land market. Prior research has examined woody vegetation's impact on urban and suburban property values (Sander et al. 2010; Pandit et al. 2012). Other studies have examined the effect of natural amenities on agricultural land, which focuses on recreational access, proximity to cities, and climate (Bastian et al. 2002; Uematsu and Khanal 2013). Borchers et al. (2014), used USDA June Area Survey data to examine how tree cover influences cropland and grassland values alongside the other previously mentioned natural amenities.

This paper investigates how woody encroachment affects agricultural land values across grasslands in Kansas, a region with ever increasing concern of woody expansion. Using parcel-level land sales data and satellite-derived measures of woody cover, a hedonic pricing model is estimated to identify how woody vegetation is capitalized into agricultural land values. This study contributes to the ongoing discussions of woody encroachment in environmental and agricultural economics by linking ecological transformations to economic outcomes.

Using a hedonic pricing framework applied to transaction-level land sales data from 1990 to 2024, we find that woody cover is capitalized positively into Kansas grassland transaction prices at currently observed levels of encroachment. A one percentage point increase in woody cover is associated with approximately a 0.66% increase in price per acre on average. However, this relationship is found to be nonlinear; the marginal valuation of woody cover diminishes as encroachment levels increase, with an inflection point of 35% woody cover beyond which additional cover begins to reduce land value at the margin. These findings are consistent with recreational buyers, particularly those motivated by hunting lease income and wildlife amenity value, driving the positive capitalization of woody cover in the land market. Survey evidence reveals a disconnect between landowner concern and observed market impacts: while over 80% of respondents identify woody encroachment as a problem, 69% report no observed effect on pasture values or rental rates. Together, these results suggest that private market incentives alone are unlikely to motivate sufficient encroachment control, providing justification for public programs such as the Kansas Great Plains Grassland Initiative (KGPGI).

Chapter 2 - Background

There has been a directional shift over the last century toward increased woody vegetation worldwide (Londe et al. 2022). The tree and shrub species responsible for this shift include not only non-native species introduced accidentally or strategically but also native species expanding their density and range in response to environmental change (Archer et al. 2017). In the United States' grasslands, humid regions provide ideal conditions for tree proliferation, while more arid savanna regions tend to experience greater shrub expansion. In both cases, this process, commonly referred to as woody encroachment, represents the gradual replacement of herbaceous grassland vegetation with woody plants. While woody encroachment is occurring globally, it is particularly consequential in the Great Plains of the United States, where grasslands have both ecological function and agricultural production.

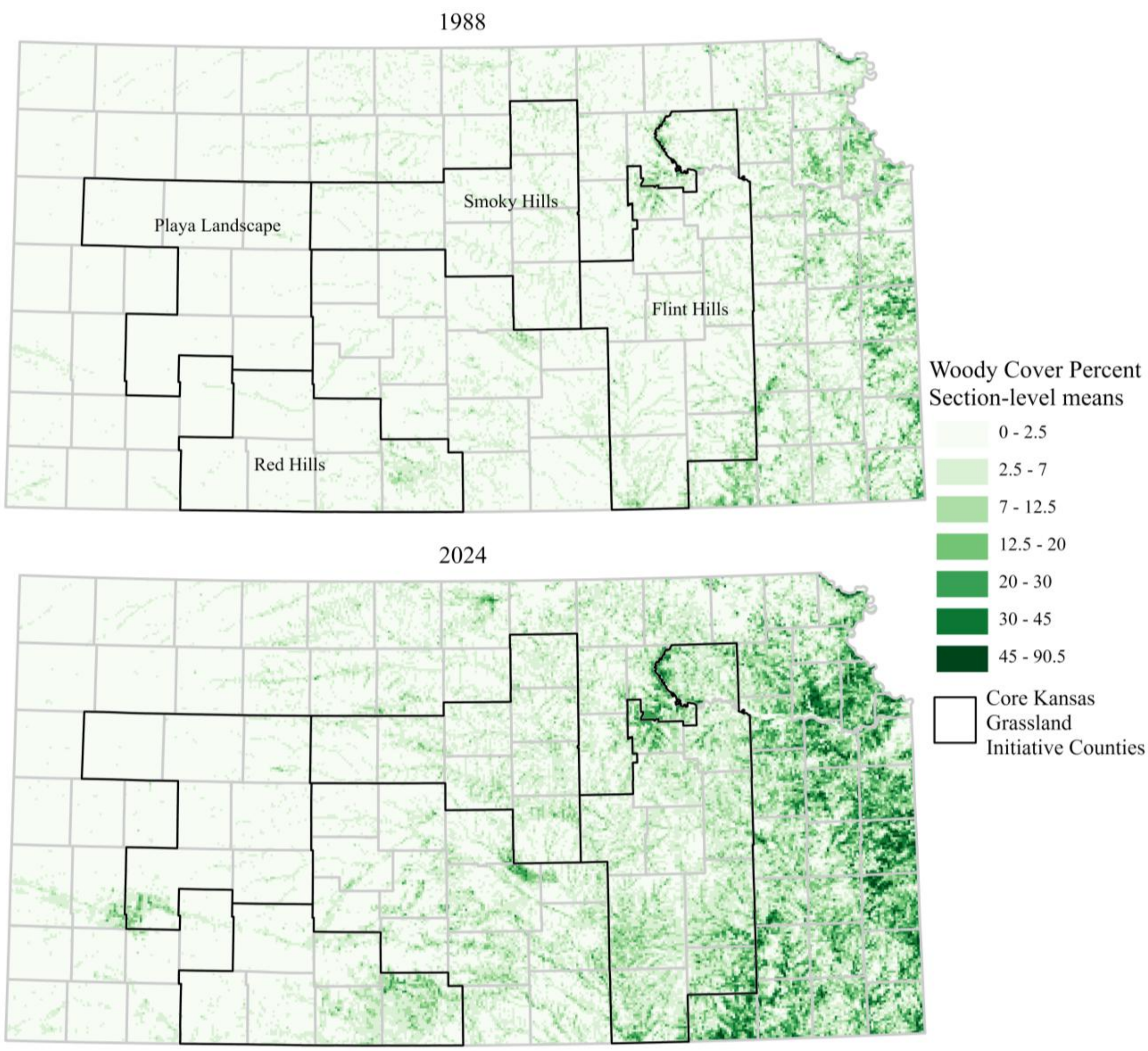
2.1 Woody Encroachment in Kansas

The Great Plains region covers all of Kansas and substantial portions of several other states in the U.S. and provinces in Canada. The western, central, and eastern portions of Kansas are generally characterized by shortgrass prairie, mixed-grass prairie, and tallgrass prairie, respectively. The Great Plains regions have seen a larger increase in woody cover compared to other regions in the United States—woody encroachment risk within the Great Plains is five-to-seven times larger relative to ecoregions outside (Barger et al. 2011). This heightened risk makes managing and preventing woody encroachment across Kansas particularly challenging and urgent.

Recognizing the ecological and agricultural problems stemming from woody encroachment in Kansas, the National Resources Conservation Service (NRCS) launched the Kansas Great Plains Grassland Initiative (KGPGI) in 2019. The primary objective of KGPGI is to slow and/or reverse woody encroachment in priority areas of the state. Priority areas include, but are not limited to, the Flint Hills, Smoky Hills, Red Hills, and the Playa Landscape ecoregions. Agricultural producers in these priority areas are eligible to receive financial incentives to undertake efforts aimed at mitigating woody encroachment along with scientific guidance in grassland management practices. The specific regions eligible for benefits under KGPGI are outlined in the upper panel of Figure 3. The lower panel of Figure 3 illustrates the change in woody cover (defined as proportion of ground covered by woody species) across

Kansas from 1988 to 2024, which is our study time period, using data obtained through the Rangeland Analysis Platform (RAP).[5] Counties located within the four outlined ecoregions in Figure 3 have been targeted by the KGPGI as priority areas and constitute the focus of this study.

Figure 3. Woody Cover Map of Kansas (1988 and 2024)



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5 The Rangeland Analysis Platform (rangelands.app) combines satellite imagery and vegetation measurements from the Bureau of Land Management, National Park Service, and NRCS to produce vegetation maps.

Looking at Figure 3, the Flint Hills and Red Hills ecoregions are observed to have experienced the most prominent increase in woody cover between 1988 and 2024. The Playa Landscape region has experienced localized encroachment, primarily in the vicinity of the Arkansas River (southwest corner of the ecoregion) where woody cover has increased upwards of 20%. Woody encroachment is a particular concern in this ecoregion due to dependence on the High Plains Aquifer and the negative effects woody vegetation on groundwater recharge (Zou et al. 2018). Woody encroachment into the Red Hills ecoregion is largely clustered within the southeastern corner (e.g., Medicine Lodge, KS) where increases in woody cover upward of 25% can be observed from 1988 to 2024.

2.2 Negative Effects of Woody Encroachment

Woody encroachment into grasslands and savannas can lead to a variety of negative impacts that are particularly concerning for Kansas's rangeland ecosystems. The spread of woody vegetation reduces forage available to livestock (Fuhlendorf et al. 2008), directly limiting the carrying capacity of grazing lands that support much of the state's beef cattle industry. It also reduces rates of groundwater recharge (Zou et al. 2018), and increases competition for soil moisture, intensifying drought vulnerability in areas that depend primarily on rainfall rather than groundwater (Torquato et al. 2020). Woody encroachment also reduces biodiversity by displacing native prairie grasses and forbs and altering habitat conditions for grassland-dependent species (Ratajczak et al. 2012). Additionally, dense woody vegetation increases the propensity for large and severe wildfires (Donovan et al. 2020), posing risks to property, livestock, and rural communities where wildfire threats already exist. Together, these effects threaten the ecological integrity and economic stability of Kansas grasslands, which depend on healthy, open rangelands for both ecosystem services and agricultural production.

The forage loss in Kansas in 2019 resulting from woody encroachment on grasslands was estimated to be 1.5 million tons. Of the ten Great Plains states, only Oklahoma and Texas lost more forage. The loss of forage in Kansas is equal to roughly 2.5 million hay bales, which is enough to support 322,000 cows. The estimated cost in terms of livestock feed was approximately $30 million (Fogarty et al. 2023). These productivity losses are important due to the large impact the beef cattle ranching industry has on the Kansas economy. In 2022, beef cattle ranching and farming had a total output of $14 billion and employed over 45,000 individuals in Kansas (Kansas Department of Agriculture 2022). As agriculture serves as a cornerstone of the Kansas economy, continued woody encroachment poses risks not only to the agricultural sector itself but also to the broader economic stability and rural livelihoods it supports.

2.3 Positive Effects of Woody Encroachment

Potential benefits of woody encroachment are primarily in the recreational space. Landowners enjoy nonmarket benefits such as aesthetics, hunting, and more (Hruska et al. 2017). There are numerous motivations for owning land in Kansas. One primary motivation is income generation from commercial agriculture. However, recreational motivations for owning land—either in conjunction with agricultural production or separate from agricultural production—is increasing (Nickerson et al. 2012; Macaulay 2016; Towe and Chen 2023). Landowners whose motivation is primarily driven by recreation source most of their income from off-farm sources, so economic viability is less of a concern compared to landowners sourcing their income from on-farm (Nickerson et al. 2012). Recreationally-sourced income (e.g., hunting leases) have been attributed to increases in agricultural land values (Damona and Brorsen 2011; Nickerson et al. 2012).

A main component of recreational income is hunting leases that can be sold to hunters or hunting enterprises (e.g., guide services/outfitters) (Munn et al. 2011). Whitetail deer in Kansas are plentiful and can reach trophy size in the eyes of hunters. Lease terms for deer hunting access can be especially lucrative to landowners (Mensah and Elofsson 2017). For species such as whitetail deer, woody covers provide habitat, or the perception of habitat, and hunting opportunities (e.g., locations for tree stands), thus making the land more valuable in the hunting space. Land possessing woody cover may be bid up on the land market by buyers whose primary motivation is recreation. Moreover, land possessing woody cover may be attractive to hunting enterprises and one would expect any lucrative lease opportunities would be capitalized in the land value (Borchers et al. 2014).

While increasing tree cover may improve recreation and aesthetics, it often reduces agricultural productivity (Towe and Chen 2023). This creates tension between production-focused landowners, who rely on open grasslands for grazing, and amenity- or recreation-focused landowners, who prefer more wooded landscapes for their beauty or for the perceived increase in supporting game species. For example, ranchers concerned with forage loss may view woody encroachment as a direct economic threat, whereas recreational landowners may perceive the same vegetation as an asset that increases wildlife presence and hunting opportunities. Divergence in land-use objectives has been shown to produce differing management behaviors and willingness to invest in control measures against threats to production (Haggerty and Travis 2006).

Chapter 3 - Materials and Methods

This study draws on multiple sources of information to evaluate landowner perspectives of woody encroachment and how woody cover influences grassland values in Kansas. The survey data provides insights into the prevailing motivations for owning land in Kansas, factors affecting the control of woody encroachment, and any market impacts observed by respondents. The transaction-level data allows for empirical estimation that can quantify the capitalization of woody cover into land values. Together, the data provide a more complete understanding of encroachment and its effects across Kansas grasslands.

3.1 Survey Data

Surveys were administered in-person and through the mail. The in-person surveys were targeted to a combination of producers, farm managers, community members, and land appraisers. The mail surveys were sent to landowners located in the counties outlined in Figure 3.

3.1.1 Workshop Surveys

In-person surveys were administered at seven meetings and workshops between February 2023, and June, 2024. The in-person events were attended by a combination of landowners, farmers, ranchers, rural appraisers, and community members and is summarized in Table 7. In total, we obtained 163 returned surveys from these events.

3.1.2 Mail-In Surveys

The mail survey was mailed to landowners located across the 33 counties outlined in the priority ecoregions in Figure 4 in late March and early April of 2025. Mailing addresses for landowners in Kansas were obtained from DTN.[6] We restricted potential respondents to landowners having at least 80 acres of agricultural land. The DTN farm panel data does not decipher between grassland and cropland in the agricultural acreage. We dropped potential

[6] https://www.dtn.com/agriculture/

Table 7. Summary of In-Person Survey Events

Event	Date	Location	Type of attendee
Kansas Society of Farm Managers and Rural Appraisers Winter Meeting	February 15-17, 2023	Hays, KS	Rural appraisers, farm managers
Livestock Learning Roadshow	March 15, 2023	Washington, KS	Farmers, ranchers
Ag Professionals Symposium	August 3-4, 2023	Kansas City, MO	Rural appraisers, farm managers
Kansas State University Risk and Profit Conference	August 17-18, 2023	Manhattan, KS	Farmers, ranchers, landowners
Prescribed Burn Workshop	February 26, 2024	Ottawa, KS	Farmers, ranchers, landowners
Mid America Farm Expo	March 20-22, 2024	Salina, KS	Farmers, ranchers, community members
Brush Management Field Day	June 13, 2024	Stockton, KS	Farmers, ranchers

respondents if the address listed a PO box or apartment number due to concerns that such addresses would be located off-farm. After dropping these potential respondents, we sampled across the 33 counties randomly according to the proportion of farms located in each county relative to the total population of farms across all 33 counties. Our survey budget allowed a total of 3,000 surveys to be printed and mailed. Our stratified random sampling strategy consisted of choosing $s_i \times 3{,}000$ addresses within each of the 33 counties at random, where s_i is the proportion of farms within county i relative to the total number of farms in all 33 counties. In other words, our sampling strategy selected more mailing addresses in counties having more farms and fewer mailing addresses in counties having fewer farms.

Postcards were mailed about one week prior to the survey. The postcard informed the recipient that the survey would be arriving and that the purpose of the survey was to collect information from landowners on woody encroachment management. Surveys were sent along with pre-addressed and stamped return envelopes. The survey included a factoid on forage losses associated with woody encroachment in Kansas from Fogarty et al. (2023). The survey included questions on motivations for owning land in Kansas, perceived severity of woody encroachment in grasslands in the vicinity of their operation, and factors perceived to be associated with difficulties in controlling woody encroachment. A total of 647 completed surveys were returned between April and September of 2025 for a response rate of 21.6%.

3.2 Empirical Data

This paper draws the data used for empirical analysis from multiple sources at the finest spatial resolution possible. Table 8 presents the summary statistics of the variables used in the empirical estimation. The next sections detail each source of data.

Table 8. Summary Statistics of Variables of Interest (N = 20,008)

Variable (unit)	Mean	Median	St. Dev.	Min	Max
Real Price per Acre (dollar/acre)	1,560.90	1,227.57	1,148.88	82.65	14,225.60
Tree Cover (%)	2.93	1.11	4.87	0	67.47
Total Parcel Acreage	248.56	157.5	313.82	40	4,953.60
Dryland (% of Land)	0.51	0.55	0.4	0	1.01
Grassland (% of Land)	0.46	0.41	0.4	0	1
Avg. Water Deficit	16.42	16.27	7.42	-1.22	36.38
Degree Days > 34C	16.08	15.1	7.99	1.57	55.57
Degree Days 10-34C	2,299.38	2,303.72	125.32	1,809.51	2,740.34
Slope (%)	3.95	3.34	2.64	0	26.99
Clay (% of Land)	31.75	29.66	8.56	3.15	58.67
Sand (% of Land)	16.39	10.74	15.13	2.93	94.59
Silt (% of Land)	51.86	52.58	10.24	2.26	67.81
Soil Organic Carbon (0-100 cm)	9.32	8.9	2.67	0.82	19.4
# Parcels in Transaction	1.5	1	1.09	1	32

3.2.1 Transaction-Level Land Sales

This paper utilizes transaction-level land sales data for every agricultural land transaction in the core funding counties of the KGPGI that is greater than 40 acres in size from 1990 to 2024 obtained from the Property Valuation Division (PVD) of the Kansas Department of Revenue. The PVD data provides information on the type of transaction (e.g., arms-length or otherwise), acreage by land type (e.g., cropland or grass), and estimated value of improvements on the land.

We restrict the analysis to arms-length transactions using validity codes in the PVD data and aggregate any parcel-specific values and characteristics up to the transaction-level for multi-parcel sales. We define and omit outlier transactions following the method in Edwards et al. (2025). We also omit transactions listing any irrigated cropland within the transaction because we are primarily interested in the impacts to grassland and mixed cropland-grassland. We also drop transactions if they have total acreage greater than 5,000 acres or total appraised values of improvements greater than $100,000. These restrictions leave 20,008 observable transactions. Transaction values are converted to 2024 values using the consumer price index.

3.2.2 Parcel Boundaries

The PVD land transaction data does not provide precise geodata. In some cases, a point coordinate is included with the transaction, but the location of the point coordinate within the observed transaction is not always consistent (i.e., center of parcel vs. edge of parcel). Moreover, relying on a point coordinate to merge land cover data to the transaction would likely introduce substantial measurement error in the ultimate empirical analysis. We rely on parcel boundary geodata to match measures of woody cover to the land transaction with accuracy. Parcel boundary data is obtained from Regrid.[7] The Regrid data provides parcel boundary polygons and an identification number for each parcel that is used by county assessors to find owners and for tax assessments. We normalize the parcel identification numbers across counties in the Regrid data and likewise for the PVD transaction data. We are unable to match parcel identification numbers between the Regrid and PVD data for Pottawatomie and Sedgwick counties and we therefore omit land transactions in these counties from the analysis.

3.2.3 Woody Cover Measures

Year-level woody cover estimates for the years 1990-2024 are obtained from RAP. The RAP data utilizes satellite imagery at a 30-meter spatial resolution which allows for a fine-grained characterization of vegetative tree cover across Kansas counties.[8] Importantly, the RAP data provides high resolution satellite imagery that varies across years, allowing our empirical

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[7] https://regrid.com

[8] The Rangeland Analysis Platform offers a 10-meter spatial resolution layer however it only dates to 2018.

model to exploit spatial and temporal variation in woody cover. We equate band 6 of the RAP data to woody cover, as has been done in other studies characterizing tree invasion into grassland systems (Scholtz et al. 2025). Year-level raster files for the woody cover RAP data are overlain with parcel boundary polygons using spatial intersection features in QGIS. We compute summary measures of the area of each parcel that is composed of woody cover (i.e., ranging from 0% to 100% of the parcel area). This information is then linked to the land transaction data using a parcel identification number.

3.2.4 Soil and Topography Characteristics

Soil characteristic data was obtained from the Soil Survey Geographic Database (SSURGO) soil survey on the website of the NRCS.[9] The PVD data contains information on parcel acres for each SSURGO soil type. The soil types are then linked to the SSURGO data which provides information of the characteristics of each soil type, which is then aggregated to the parcel-level. The soil variables included in our analysis are clay content, silt content, sand content, the organic matter content in the soil, and the slope. These attributes together control for soil texture, fertility, and topography, all of which can affect the productivity and utility of agricultural land.

3.2.5 Climate

Weather data at the grid-cell level are obtained for Kansas from PRISM.[10] We construct four climate variables from the PRISM data: growing season precipitation, growing season reference evapotranspiration, the number of growing season degree days between 10C and 34C, and the number of growing season degree days above 34C. We define the growing season as

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[9] Soil data can be accessed through the web soil survey (https://websoilsurvey.nrcs.usda.gov)

[10] https://prism.oregonstate.edu

April 1 – September 30. We then compute a water deficit variable as the difference between evapotranspiration and precipitation. Each climate variable is computed as a rolling five-year average up to the year of the land transaction. The climate variables are linked to land transactions by matching the centroid of the parcel boundary to the centroid of the nearest grid-cell.

3.3 Hedonic Models Estimated

Land values are modeled using a hedonic pricing framework. The conceptual basis of the hedonic model is that the price of a parcel can be expressed as a function of its characteristics (Rosen 1974). The fundamental asset market equation states that in a competitive land market, agricultural land value will reflect the present discounted value of the stream of current and future rents (Plantinga and Miller 2001).

The hedonic price function incorporates three categories of parcel attributes: woody cover exposure z^w, land and soil characteristics z^s, and climate variables z^c. These attributes collectively form a vector of characteristics that determines the observed market price for parcel i, as shown in expression (A):

$$P(z_i) = P(z^w, z^s, z^c) \tag{1}$$

To estimate the contribution of each component of the vector z_i to land value, a semi-log functional form is specified, allowing coefficient estimates to be interpreted as the proportional change in price per-acre resulting from marginal changes in each component. This is estimation model (1):

$$\ln\left(\frac{Price}{Acre}\right)_{it} = \beta_w z_{it}^w + \Gamma_s{}' Z_{it}^s + \Gamma_c{}' Z_{it}^c + \eta_t + \gamma_c + \varepsilon_{it} \tag{1}$$

Where the dependent variable, $\ln(\text{Price/Acre})_i$ is the natural logarithm of the observed sale price per acre for transaction i. The parameter β_w is a coefficient for the continuous variable of woody cover on the given parcel. The terms Γ_s and Γ_c are coefficient vectors to be estimated, reflecting the marginal contribution of each attribute category, soil and land characteristics, and climate variables respectively, to land value. The error term, ε_i captures unobserved heterogeneity and measurement error.

To control unobserved heterogeneity that may inflict bias in the coefficient estimates, fixed effects for both year (η_t) and township (γ_c) are included in the regression. The implementation of year fixed effects accounts for shocks to grassland value each year, such as policy, macroeconomic conditions, or commodity prices. Township fixed effects are used to capture time-invariant township characteristics, such as population, proximity to infrastructure, or regional land quality.

Another estimation model is ran that includes both linear and squared terms for the woody cover term. This allows for potential non-linear relationships between grassland value per acre and woody cover. This is due to prior literature expressed in the introduction, where low to moderate levels of tree cover can be used for recreational purposes, however excessive tree cover can result in reduced forage productivity and decrease ecosystem biodiversity. This is estimation model (2):

$$\ln\left(\frac{Price}{Acre}\right)_{it} = \beta_{1w} z_{it}^{w} + \beta_{2w}(z_{it}^{w})^2 + \Gamma_s{}' Z_{it}^{s} + \Gamma_c{}' Z_{it}^{c} + \eta_t + \gamma_c + \varepsilon_{it} \tag{2}$$

Chapter 4 - Results

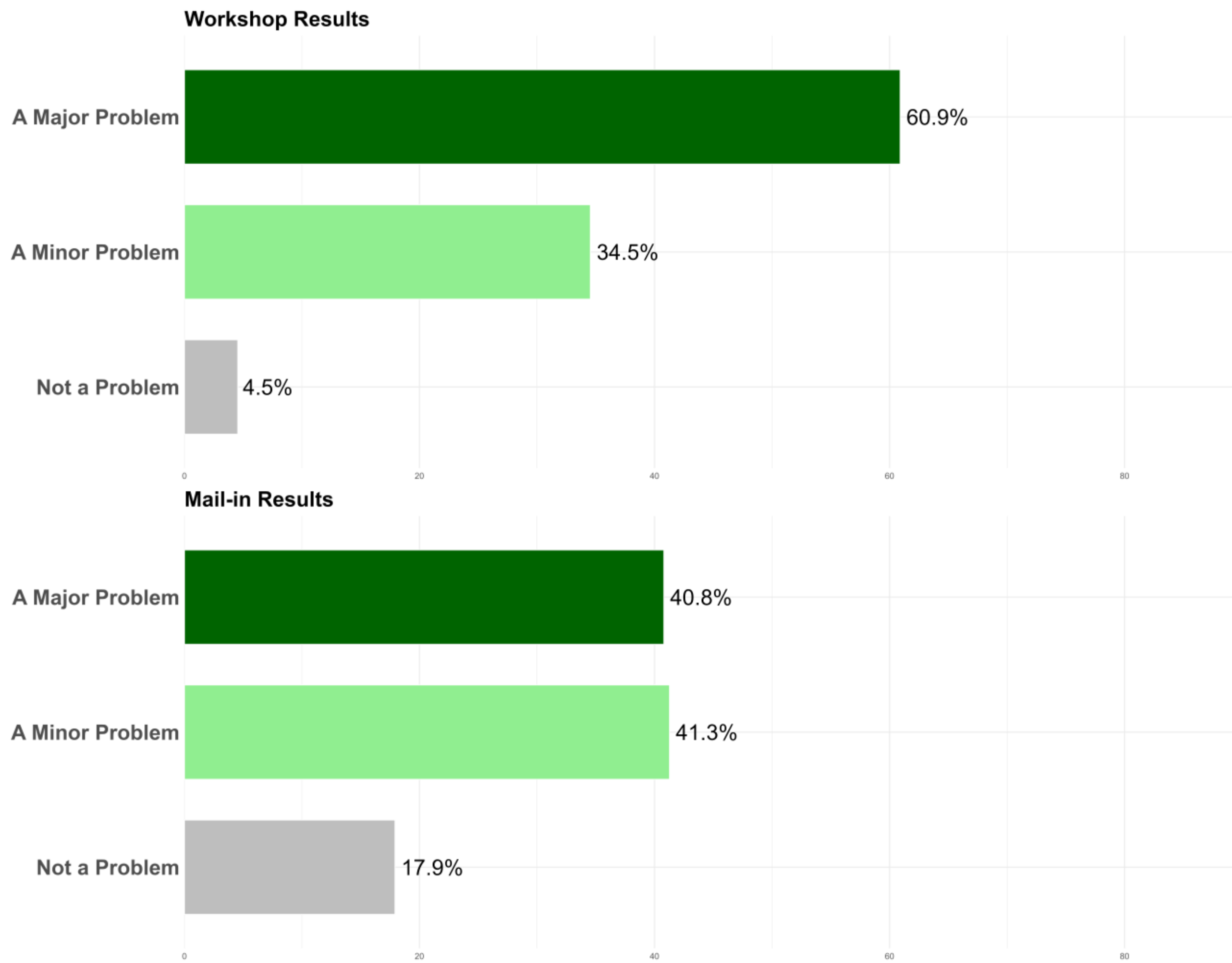
The results are presented in two parts. The first part presents the findings from the workshop and mail-in surveys, which describe landowner perceptions of woody encroachment and their opinions on how it affects land values. The second part presents the two hedonic models estimation results, which quantifies the capitalization of woody cover on grassland transaction prices.

4.1 Survey Results

Survey responses were collected from both workshop attendees and mail-in respondents across the four KGPGI priority ecoregions and across the workshops outlined in Table 3. The workshop surveys captured perspectives and insights from landowners, farmers, ranchers, rural appraisers, farm managers, and community members attending events across the state of Kansas. The mail-in survey targeted landowners operating within the 33 counties spanning priority ecoregions.

Respondents across both the workshop and mail-in surveys were asked about how they viewed woody encroachment near their operation or community. Figure 4 shows the response distribution across the following answers: A Major Problem, A Minor Problem, or Not a Problem. A majority of respondents in both surveys indicated that it was a major or minor problem, with 95.4% of respondents stating that in the workshop survey and 82.1% of respondents across the mail-in surveys. The workshop survey respondents showed a larger concern towards woody encroachment, with 60.9% of responses being a major problem compared to the 40.8% of mail-in respondents who expressed it was a major problem. Respondents across both the workshop and mail-in surveys had similar distribution of responses being woody encroachment is a minor problem, 34.5% and 41.3%, respectively. The biggest difference in the responses comes from the distribution of respondents who stated that woody encroachment severity is not a problem near their operation. In the workshop survey results, only 4.5% of respondents stated that whereas in the mail-in survey results, 17.9% of respondents did.

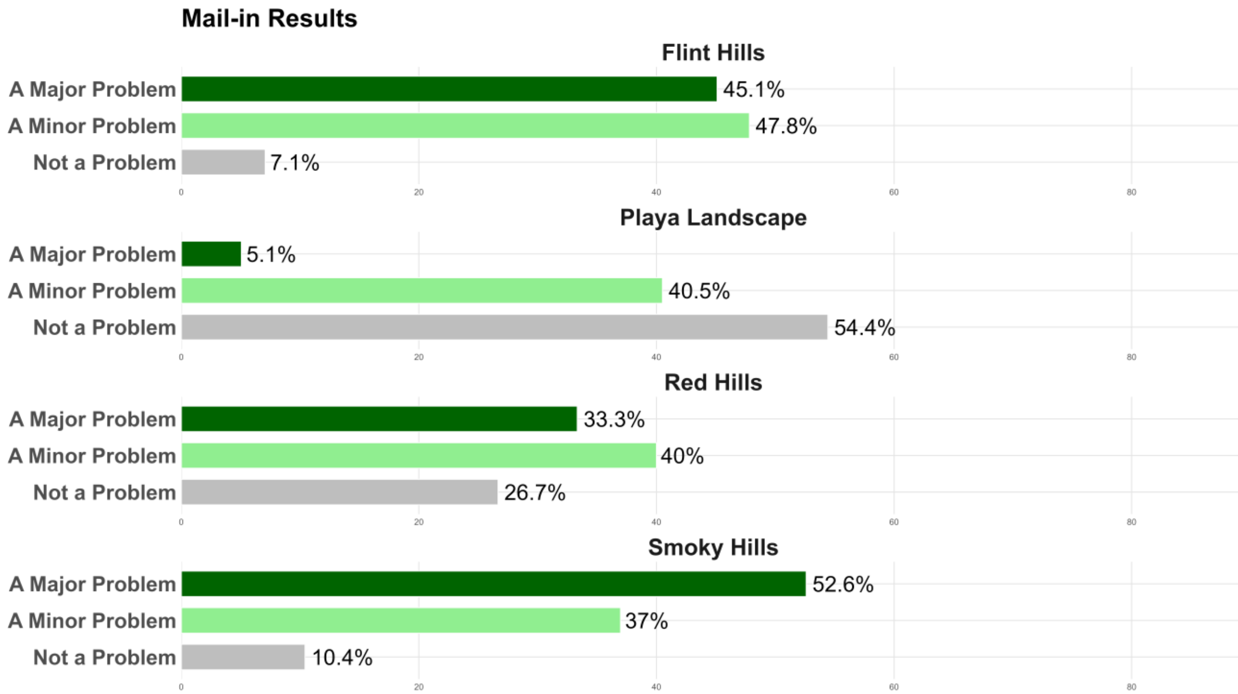
Figure 4. Respondents Rating of Woody Encroachment Severity Around their Operation, Split between Workshop Responses and Mail-In Survey Response



Note: 110 workshop respondents and 625 survey respondents for this question.

Figure 5 splits the responses from the mail-in surveys into what ecoregion the respondent operates within to see how the response differs based on the location of the operation. Respondents operating within the Flint Hills and Smoky Hills ecoregions reported the highest rates of serious concern and also the lowest rate of not a problem responses. This is consistent with the substantial increases in woody cover observed within these two ecoregions shown in Figure 1 from 1988 to 2024. Respondents in the Red Hills had a very mixed response split,

Figure 5. Mail-In Responses of how Severe Woody Encroachment is Around their Operation, Split by Ecoregion of Respondent



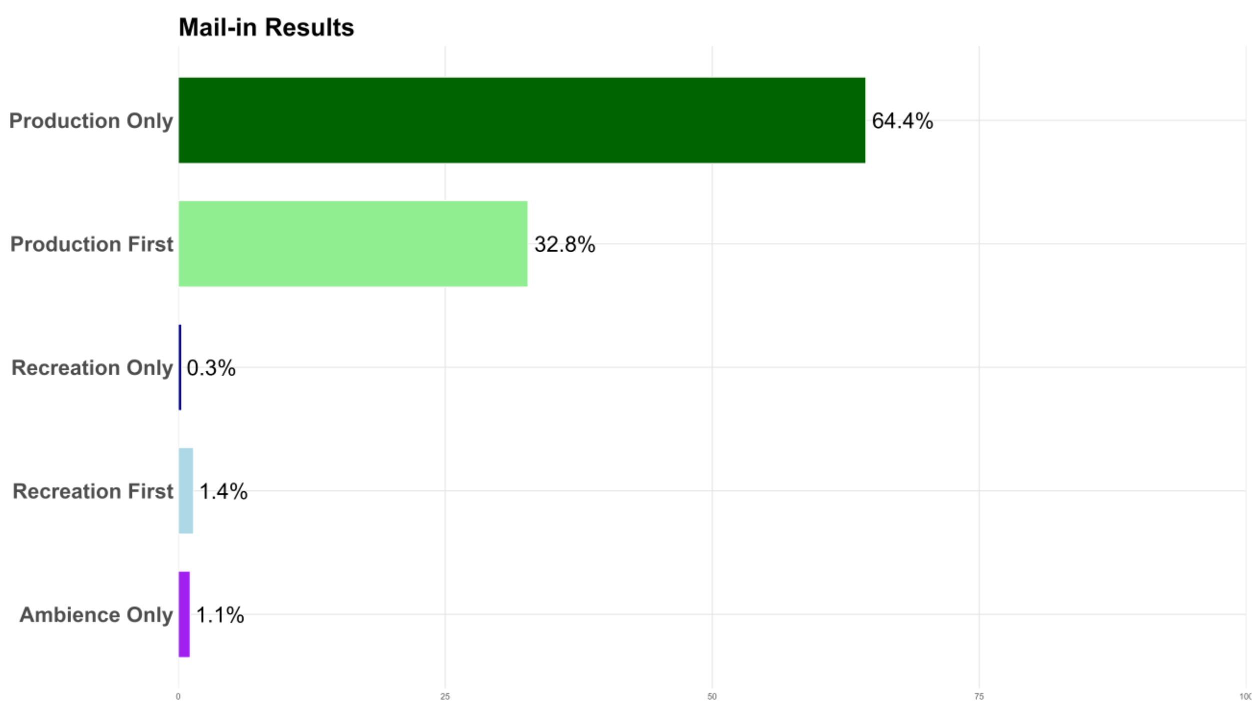
Note: 515 total responses, 184 from the Flint Hills, 79 from the Playa Landscape, 60 from the Red Hills, and 192 from the Smoky Hills. The difference from Figure 2 responses reflects respondents who did not report a county of operation or reported a county outside of ecoregions

where 33.3% stated it was a major problem, 40% said it was a minor problem, and 26.7% said it was not a problem. This reflects how in the Red Hills, there are pockets of woody encroachment concerns whereas in other parts of the ecoregion it is not prevalent, which is also shown in Figure 1. Respondents from the Playa Landscape represent the largest amount of a minor problem and not a problem responses, 40.5% and 54.4%, respectively. With only 5.1% of respondents claiming it was a major problem near their operation. This illustrates how woody encroachment in the Playa Landscape is a localized concern like described in Section 2.1 but has not had substantial increases from 1988 to 2024 like other parts of the state.

Figure 4 presents mail-in respondents' primary purpose for owning land in Kansas. A substantial majority of the responses are either production only or production first, with recreation being a secondary benefit, with 64.4% and 32.8% of total responses, respectively. However, there are still some respondents who answered either recreation only, recreation first, with agricultural income as a secondary benefit, and ambience/beauty of living in the country only, with 0.3%, 1.4%, and 1.1%, respectively. Knowing this distribution of what Kansas landowners' purpose for owning agricultural land is crucial for understanding how woody cover impacts grassland values.

Figure 7 presents survey results on respondents' perceptions of how woody cover affects pasture and grassland values. Workshop respondents, which included rural appraisers and farm managers, were asked how 20%, 40%, and 60% tree cover would affect market value of pasture and grassland (This question was only asked in two of the workshops). Across all three cover levels, the most common response was that tree cover would cause a slight or strong decrease in land value, with the share of respondents expecting a decrease rising from 41.7% at 20% cover to

Figure 6. Mail-In Response when asked about their primary purpose for owning land



55.6% at 60% cover. The share expecting no meaningful impact fell sharply from 36.1% at 20% cover to 5.6% at both 40% and 60% cover, suggesting that higher levels of woody cover are broadly seen as having a meaningful market effect. A strong minority of respondents expected an increase in land value at higher cover levels, 22.2% at 20% cover rising to 41.7% at 40% cover, likely reflecting recreation- and amenity-oriented perspectives on wildlife habitat value. Among mail-in respondents, 69% reported having not experienced or observed any impacts on pasture land values or rental rates due to woody encroachment. Of those who did observe an impact, 21.6% perceived a decrease and 9.4% perceived an increase.

Tables 9 and 10 summarize the factors respondents identified as most contributing to the difficulty of controlling woody encroachment, from the mail-in and workshop surveys respectively. Across both survey results, labor limitations and cost of control emerged as the two most frequently cited barriers. Over half of the mail-in respondents, 52.2%, identified labor limitations as the top factor, and 42.9% cited that cost of control as a top factor. The workshop survey results had similar patterns, where labor limitations were selected 57.7% and cost of control by 52.1% of respondents. In addition to these factors, both the mail-in and workshop respondents also cited the difficulty of prioritizing where to allocate woody encroachment control given limited resources, with 38.7% of respondents in both the mail-in survey and the workshop survey.

Liability and risk associated with prescribed burning, a practice used to help control woody encroachment, was a notable barrier cited in both surveys, with 26.9% of mail-in respondents and 25.8% of workshop respondents. The impact of neighboring landowners as well was cited in both surveys as a factor: 31.3% of mail-in respondents and 18.4% of workshop respondents stated that absent or unengaged landowners contributed to the difficulty of woody

Table 9. Factors Contributing to the Difficulty of Controlling Woody Encroachment Responses from Mail-In Survey

Top factors contributing most to the difficulty of controlling tree/brush encroachment	n	%
Deciding where to prioritize control treatments for greatest benefit given resource limitations	220	38.7%
Cost of control, including lack of or difficulty applying for cost-share programs	244	42.9%
Labor limitations, to get started, including limited time and equipment/crew availability	297	52.2%
Lack of information regarding which control techniques are the most effective/appropriate	56	9.8%
Past control efforts have been ineffective or had short duration benefit	62	10.9%
Liability/risk/fear association with prescribed burning and/or lack of training and experience with prescribed burning	153	26.9%
Perceptions by neighboring landowners that tree and brush cover benefit wildlife/ecosystem or are "natural" for this ecosystem, leading to reluctance to control woody species	73	12.8%
Absent/unengaged landowners with minimal interest/investment in land management improvement activities	178	31.3%
Other	83	14.6%

Note: 569 total responses for this question.

Table 10 Factors Contributing to the Difficulty of Controlling Woody Encroachment Responses from Workshop Surveys

Top factors contributing most to the difficulty of controlling tree/brush encroachment	n	%
Cost of control	85	52.1%
Labor limitations	94	57.7%
Perceptions that tree/brush cover are beneficial to wildlife/ecosystem/etc.	75	46.0%
Management is impacted by the actions/inactions of neighboring landowners	45	27.6%
Lack of information regarding which control techniques are the most effective/appropriate	18	11.0%
Prioritizing which areas to treat given resource limitations	63	38.7%
Ineffective treatment techniques	17	10.4%
Liability/risk/fear of burning	42	25.8%
Absent/unengaged landowners	30	18.4%

Note: 163 total responses to this question throughout the workshops.

encroachment control. The workshop survey respondents also stated that management of woody encroachment is impacted by actions or inactions of neighboring landowners, 27.6%. A meaningful share of workshop respondents, 46%, also cited perceptions among neighboring landowners that tree and brush cover are beneficial to wildlife or the ecosystem, whereas only 12.8% of mail-in respondents cited the same.

4.2 Hedonic Estimation Results

The regression results for both estimation models are presented in Table 5. Both models exhibited a strong overall fit, with R-squared values of 0.672 and 0.673 for Models 1 and 2 respectively. This suggests that the included woody cover, land use, soil, topography, and climate variables explain approximately 67 percent of the variation in log grassland transaction price per acre. The within R-squared values of 0.559 across both models indicated that much of the share of variation is explained by the transaction-level covariates alone, net of the township fixed effects.

The control variables had results that are broadly consistent with prior hedonic land value literature. Native grassland proportion carried a negative and statistically significant coefficient across both models, reflecting the lower price per-acre market value compared to that of mixed-use transactions with dryland crop acreage. Tame grassland proportion was positive and statistically significant, reflecting that improved pasture commands a premium over dryland crop acreage. The slope coefficient was negative and statistically significant, aligning with expectations that more rugged and less flat reduces agricultural utility and land value. The climate variables had expected results, with water deficit exerting a statistically significant negative effect on land value and moderate degree days carrying a positive and significant

Table 11. Regression Results from Linear (1) and Nonlinear (2) Hedonic Models

	(1)	(2)
Woody Cover (%)	0.00656***	0.01209***
	(0.00112)	(0.00214)
Woody Cover Squared	-	-0.00017***
		(0.00005)
Native Grass (%)	-0.08351***	-0.07680***
	(0.01884)	(0.01838)
Tame Grass (%)	0.10229***	0.10136*
	(0.03743)	(0.03739)
Avg. Water Deficit	-0.00801**	-0.00786**
	(0.00383)	(0.00381)
Degree Days > 34C	-0.00599	-0.00589
	(0.00359)	(0.0036)
Degree Days 10-34C	0.00106***	0.00105***
	(0.00026)	(0.00026)
Slope (%)	-0.00858***	-0.00866***
	(0.00282)	(0.00283)
Sand (%)	0.00674***	0.00616***
	(0.00152)	(0.00155)
Silt (%)	0.00745***	0.00688***
	(0.00201)	(0.00204)
Soil Organic C (0–100cm)	0.01603***	0.01494***
	(0.00461)	(0.00453)
# Parcels in Transaction	-0.02137***	-0.02150***
	(0.00479)	(0.00481)
Spatial Control	Township(743)	Township(743)
Observations	11298	11298
R2	0.672	0.673
R2 Within	0.559	0.559
RMSE	0.402	0.402

Note: Significance Codes: *p < 0.10, **p < 0.05, ***p < 0.01

coefficient. Soil composition, sand, silt, and soil organic carbon, had all positive and statistically significant coefficients, consistent with studies finding that soil texture and fertility influence grassland values when forage productivity is an important factor (Meissner and Musshoff 2022; Tavares et al. 2022). The number of parcels in a transaction carried a negative and significant coefficient, reflecting a per-acre discount associated with multi-parcel sales. Overall, the results of the control variable coefficients align with prior hedonic land value studies and support the validity of the model specification.

Focusing on the primary variables of interests, the woody cover coefficients told a consistent story across both models. In Model 1 the coefficient of woody cover is 0.00656 and statistically significant at the 1% level. This means a one percentage point increase in woody cover in a transaction is associated with a 0.66% increase in land values on average. In Model 2, the addition of the squared term revealed a nonlinear relationship between woody cover and land value. The linear term remained positive at 0.01209 and statistically significant at the 1% level, while the squared term is negative at -0.00017 and statistically significant at the 1% level. This indicated that the positive relationship between woody cover and land value is nonlinear, where the marginal valuation of woody cover decreases as the total amount of woody cover in the transaction increases. The marginal effect of woody cover at any observed level can be computed as $0.01209 - 0.00034 \times$ woody cover, declining from approximately 1.2% per percentage point at zero cover to zero at the 35% inflection point. The inflection point implied by the joint woody cover coefficients from Model 2, where additional woody cover no longer increases land value, occurs at approximately 35.6% woody cover. However, the total capitalized effect of woody cover relative to a zero-cover counterfactual does not turn negative until approximately 69.1 percent woody cover. No transactions in the estimation sample exceed this threshold, as the maximum observed woody cover is 67.5 percent.

To examine whether the capitalization of woody cover into grassland values varies across the ecoregions of the study area, Models 1 and 2 were re-estimated for each ecoregion within the KGPGI priority counties. These ecoregion specific results are presented in Table B.1 in the

Appendix and give supplementary evidence. This table provides the linear and quadratic coefficients of woody cover estimated. The other control terms not listed are similar than those in the models estimated prior.

For the Flint Hills results, a linear specification returned a positive and statistically significant coefficient of 0.0034, consistent with what was found from the pooled Model 2 result. The quadratic specification yielded a linear term of 0.00712 and a squared term of -0.000108, both statistically significant, implying a turning point at approximately 33.0% woody cover beyond which additional woody cover begins to reduce land value at the margin. The Red Hills had a linear coefficient of 0.043 that is statistically significant and substantially larger than the Flint Hills estimate. The quadratic specification yielded a linear coefficient of 0.04283 and a significant squared term of -0.000626, implying a turning point at approximately 34.2% woody cover. The larger coefficient magnitude in the Red Hills may reflect the relatively lower baseline levels of woody cover in that ecoregion, where even modest increases in tree cover represent a more attractive parcel that recreational and amenity-oriented buyers may value more strongly. In the Smoky Hills and Playa Landscape ecoregions, woody cover coefficients had positive signs but were statistically insignificant across both specifications, suggesting that the capitalization of woody cover into grassland transaction prices is not detectable at the current levels in these ecoregions. The Playa Landscape result was consistent with the survey findings in Section 4.1, where respondents in that ecoregion reported the lowest rates of concern about woody encroachment and the lowest rates of observed impacts on land values.

Chapter 5 - Discussion and Conclusion

The results of this study provide evidence that woody cover is generally capitalized positively into grassland values across Kansas, although the magnitude of the effect depends on the level of woody cover and the local land market context. Together, the survey and empirical results suggest that the valuation of woody encroachment in the Kansas grassland market is complex, with competing motivations of production-oriented and recreation-orientated landowners, the heterogeneity of woody cover severity, and recreational demand across the state.

The survey responses reveal that Kansas landowners have broad recognition of woody encroachment as a problem within their operations, with 95.4% and 82.1% of respondents respectively identifying it as either a major or minor problem. This concern is mostly concentrated within the Flint Hills and Smoky Hills ecoregions, which is consistent with the substantial increases in woody cover documented in these regions from 1988 to 2024. Despite this widespread concern of woody encroachment, the majority of mail-in respondents, 69%, cited having either not experienced or observed any impacts to pasture land values or rental rates because of higher woody cover, with 21.6% perceiving a decrease and 9.4% perceiving an increase. The factors that contribute to the difficulty of controlling woody encroachment cited in Tables 9 and 10 help contextualize this pattern. The most cited factors from both mail-in and workshop respondents were labor limitations and cost of control. Both survey respondents also documented that neighboring absentee or unengaged landowners and neighbors who value woody cover as a positive as more factors that make controlling woody encroachment difficult. These barriers to control suggest that even landowners who perceive woody encroachment as economically harmful or a problem for their operation may not be able to act, which may contribute to the persistence and continued expansion of encroachment across Kansas grasslands.

The land ownership motivations illustrated in Figure 6 reveal a significant divide in how Kansas landowners value their property. While 64.4% of respondents own land exclusively for agricultural production, another 32.8% prioritize production but also derive secondary value from recreational access. This variation in goals creates a conflict in how woody cover is valued within the land market. For production-only owners, woody encroachment is an economic liability because it reduces forage and livestock carrying capacity. Conversely, recreation-oriented owners view the same woody cover as an asset that improves wildlife habitat and potential to generate hunting lease income. This creates a market where woody cover is simultaneously perceived as an economic discount and a premium, depending on the buyer's specific objectives.

The hedonic estimation results indicate that woody cover is capitalized positively into grassland transaction prices at currently observed levels of encroachment, with a one percentage point increase in woody cover associated with a 0.66% increase in price per acre on average from the linear model results. However, when interpreting the non-linear model woody cover coefficients, it reveals that this relationship is not constant, rather, the positive effect of woody cover on land value diminishes as encroachment levels increase, with an inflection point at roughly 35.6% woody cover. The predicted net capitalization effect relative to a zero-cover counterfactual turning negative is at 69.1% woody cover, which is a threshold that no transaction in the estimation sample exceeds.

The spatial pattern of total capitalized effects shown in Table B.1 reinforced the interpretation that recreational demand is the primary mechanism driving positive woody cover capitalization in Kansas grassland markets. The concentration of the highest capitalized values in the Flint Hills, where proximity to city centers such as Manhattan and Wichita create larger hunting lease markets and a broader pool of amenity-oriented buyers, suggests that the land market premium for woody cover is not uniform across the state but instead reflects local recreational market conditions. The lower capitalized effects observed in the Playa Landscape portion of the study area are consistent with a buyer pool that is more heavily weighted toward agricultural production, where woody encroachment is more likely perceived as a cost through forage loss than as an asset through recreational value. Together, these spatial patterns suggest that the effectiveness of public conservation programs such as the KGPGI in motivating private encroachment control may vary substantially across ecoregions, with the strongest misalignment between market signals and ecological costs occurring in the Flint Hills, where the recreational premium is largest and private incentives to control encroachment are weakest.

The inflection point implied by the nonlinear model, at approximately 35.6% woody cover in the pooled specification and 33% and 34.2% in the Flint Hills and Red Hills respectively, aligns closely with the wildlife management literature on optimal whitetail deer habitat. Extension research on rangeland deer habitat in ecologically comparable Great Plains regions identifies approximately 40% brushy cover with the remainder open grassland as the threshold for optimal deer habitat conditions (Masters and Stewart 2017). Below this threshold, additional woody cover enhances perceived habitat quality by providing cover, food, and fawning habitat that supports deer populations which could increase hunting opportunities. Habitat value for deer generally declines past 40% woody cover (American Forest Foundation 2023). This shows that the predicted land market turning point in the observed transactions closely mirror the ecologically derived optimal habitat threshold. Recreational buyers, who are particularly motivated by hunting lease income or wildlife amenity value, are capitalizing their perception of whitetail deer habitat quality in transaction prices.

Overall, these findings highlight the complexity of how woody encroachment is capitalized into grassland land markets in Kansas, where the effect is not uniform but instead shaped by local land markets, encroachment severity, and the competing productive and recreational uses of grasslands across the state. While the land market currently rewards woody cover at the observed levels of encroachment, this market signal may not persist as encroachment continues to expand across the state or becomes denser in already encroached areas. As woody cover levels increase and approach the range where the net capitalized effect diminishes and eventually turns negative. The barriers to controlling woody encroachment documented in the survey, cost, labor, coordination failures between neighbors, and absentee landowners, suggest that private incentives alone are unlikely to be sufficient to motivate landscape-scale management programs, providing justification for public conservation programs such as KGPGI. This creates an important management paradox: the KGPGI subsidizes woody encroachment control measures precisely in the regions where private land market signals are working against control. In the Flint Hills, where recreational demand for wooded landscapes is strongest and the capitalized premium for woody cover is largest, private landowners face the weakest market incentive to invest in removal. Public programs that internalize the ecological costs of encroachment, costs that are not reflected in transaction prices, are therefore most needed in the same areas where they face the greatest friction from market forces that reward woody cover.

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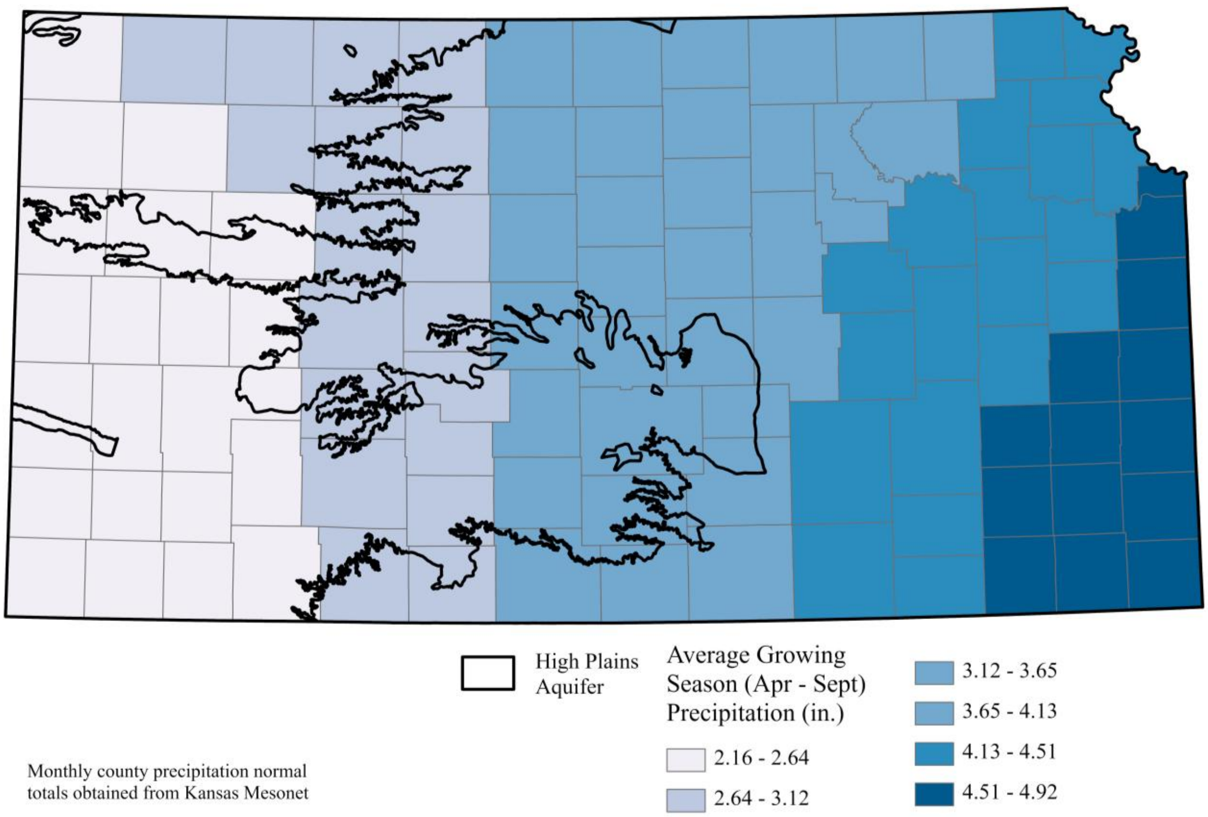
Appendix A - Essay 1

Appendix Figure A.1 Average Growing Season Precipitation for Kansas Counties



Appendix Table A.1 Regression Results with Year Fixed Effects

	Model 1 Single Dummy	Model 2 Two Dummy	Model 3 LEMA Only	Model 4 IGUCA Only
Intercept	6.88***	6.73***	9.10***	6.81*
	(0.688)	(0.700)	(2.22)	(3.63)
Any Policy	-0.076	—	—	—
	(0.091)			
Sheridan 6 LEMA	—	0.131	0.191	—
		(0.200)	(0.202)	
Walnut Creek IGUCA	—	-0.129	—	-0.116
		(0.102)		(0.123)
Dryland Proportion	0.449**	0.429**	0.575**	0.100
	(0.181)	(0.182)	(0.240)	(0.419)
Irrigated Proportion	1.45***	1.44***	1.71***	0.762*
	(0.152)	(0.152)	(0.194)	(0.393)
Clay (%)	0.007	0.006	-0.006	0.022**
	(0.006)	(0.006)	(0.018)	(0.009)
Silt (%)	-0.005*	-0.004	0.006	-0.014***
	(0.003)	(0.003)	(0.009)	(0.005)
Soil Organic Carbon	-0.004	-0.004	0.009	0.014
	(0.009)	(0.009)	(0.012)	(0.018)
Slope	-0.039***	-0.039***	0.005	-0.073
	(0.015)	(0.015)	(0.022)	(0.058)
Precipitation	-0.019	-0.015	-0.029	0.021
	(0.017)	(0.018)	(0.047)	(0.058)
Moderate Days	-0.0005	-0.0003	-0.024	-0.040
	(0.005)	(0.005)	(0.015)	(0.191)
Extreme Days	-0.002	-0.002	0.021	0.002
	(0.004)	(0.004)	(0.013)	(0.010)
Observations	515	515	387	128
R2	0.66801	0.66896	0.69603	0.77499

Significance Codes: *p < 0.10, **p < 0.05, ***p < 0.01

Appendix Table A.2 Anticipatory Sales Robustness Check Regression Results

	Model 2 Two Dummy
Intercept	-80.6*** (4.03)
Any Policy	-
Sheridan 6 LEMA	0.308* (0.168)
Walnut Creek IGUCA	-0.195** (0.095)
Dryland Proportion	0.441** (0.180)
Irrigated Proportion	1.41*** (0.151)
Clay (%)	0.004 (0.006)
Silt (%)	-0.002 (0.003)
Soil Organic Carbon	-0.006 (0.009)
Slope	-0.044*** (0.014)
Precipitation	0.018** (0.007)
Moderate Days	-0.005** (0.003)
Extreme Days	0.003 (0.002)
Year	0.044*** (0.002)
Observations	515
R2	0.62603

Significance Codes: *p < 0.10, **p < 0.05, ***p < 0.01

Appendix B - Essay 2

Appendix Table B.1 Ecoregion-Specific Regression Results, Linear and Nonlinear Hedonic Models for Woody Cover

	Linear Regression Results			
	Flint Hills	**Red Hills**	**Smoky Hills**	**Playa**
Woody Cover	0.0034**	0.043***	0.00801	0.04060
	(0.001)	(0.007)	(0.005)	(0.026)
Observations	5389	1382	3155	1372
	Quadratic Regression Results			
Woody Cover	0.007122**	0.042826***	0.008016	0.040638
	(0.002)	(0.007)	(0.005)	(0.026)
Woody Cover Squared	-0.000108.	-0.000626***	-7.30E-05	-0.002185
	(0.00006)	(0.00013)	(0.00017)	(0.00267)
Observations	5389	1382	3155	1372