Groundwater Regulation and Land Market Outcomes in Irrigated Agriculture

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Abstract

Groundwater conservation policies are increasingly used to address aquifer depletion in irrigated agricultural systems, yet their economic impacts remain uncertain. Limiting pumping may mitigate common-pool depletion and support the long-run availability of irrigation, but it can also constrain current water use and reduce returns for affected producers. This paper examines how two distinct groundwater management approaches in Kansas—the locally administered Sheridan 6 Local Enhanced Management Area (LEMA) and the state-imposed Walnut Creek Intensive Groundwater Use Control Area (IGUCA)—are reflected in irrigated cropland values. Using transaction-level land sales data and a hedonic pricing framework, we find that higher land values observed within the LEMA are explained by pre-existing differences in land quality rather than policy effects. In contrast, the IGUCA is associated with a decline in land values following implementation, though this estimate is based on a limited pre-policy sample. Thin transaction counts in key periods limit precision, and results should be interpreted as suggestive. Overall, the findings highlight heterogeneity in how alternative groundwater policies are reflected in land markets, shaped by differences in regulatory design and local context.

1. Introduction

Groundwater plays a central role in agricultural production in semi-arid regions, where precipitation is often insufficient to satisfy crop water requirements. In these settings, irrigation supported by groundwater has enabled sustained agricultural activity in areas that would otherwise be marginal for intensive cropping. However, when extraction consistently exceeds natural recharge, aquifer levels decline over time, raising concerns about the long-run sustainability of water resources and the agricultural systems that depend on them. In response, policymakers and local stakeholders have increasingly adopted groundwater management strategies aimed at slowing depletion and extending aquifer life (e.g., Perez-Quesada & Hendricks, 2021; Smith et al., 2017). These developments motivate a key question: how do groundwater conservation policies affect the value of irrigated agricultural land?

Kansas provides a useful case study of groundwater-dependent agriculture and policy responses to aquifer decline. Irrigation in the state—particularly in western Kansas—relies heavily on the High Plains Aquifer, where precipitation is substantially lower than in central and eastern regions. Groundwater is essential for crop production in this setting. For example, corn, the dominant cash crop, requires approximately 27 to 28 inches of water during the growing season, exceeding typical rainfall in western Kansas (Araya et al., 2017). Groundwater supplies roughly 96% of irrigation water in the state, supporting nearly three million irrigated acres (Kenny & Juracek, 2013). While only 15% of Kansas cropland is irrigated, it accounts for over 30% of total crop value (Rogers & Lamm, 2012), underscoring groundwater's economic importance.

Decades of groundwater withdrawals exceeding recharge have reduced saturated thickness and lowered water tables across much of western Kansas (Whittemore et al., 2018). Intensive pumping has produced localized "cones of depression"[1] and, in some areas, diminished the feasibility of high-capacity irrigation systems (Butler Jr et al., 2013; Steward et al., 2013; Whittemore et al., 2023). In response, state and local actors have pursued policies to reduce groundwater use and extend aquifer longevity. While Kansas water has historically been governed by prior appropriation (i.e., "first-in-time, first-in-right"), recent policy approaches—such as Local Enhanced Management Areas—have introduced coordinated, mandatory reductions in groundwater extraction at local scales.

[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).

These management strategies reshape the relationship between groundwater availability and agricultural land values. Historically, reliable access to groundwater increased agricultural productivity and was capitalized into higher land values (Edwards et al., 2025; Sampson et al., 2019). Under curtailment policies, however, this relationship becomes more complex. Restrictions on pumping reduce current water availability and may lower short-run returns, while potentially improving long-run aquifer conditions. As a result, land markets must balance immediate production constraints against expectations about future water availability. This valuation problem is further complicated in Kansas because curtailment policies do not always strictly adhere to water-right seniority. This introduces additional uncertainty regarding the timing and magnitude of future water access, which may weaken or obscure how groundwater policy is reflected in land values.

A substantial body of research examines how water availability is reflected in agricultural land values, typically treating water as a productive asset that is capitalized into land prices. Common measures of groundwater availability include depth to water and saturated thickness, which capture the physical accessibility and volume of groundwater (Brozovic & Islam, 2010; Fenichel et al., 2016; Hornbeck & Keskin, 2014; Ifft et al., 2018; Mukherjee & Schwabe, 2014; Sampson et al., 2019; Torell et al., 1990). These measures are particularly relevant in groundwater-dependent regions such as the HPA, where pumping costs and irrigation feasibility depend on aquifer conditions. Other studies instead use water delivery volumes or permitted extraction levels, which provide more direct measures of usable water, especially in systems with surface water allocation or binding annual pumping limits (Buck et al., 2014; Crouter, 1987; Edwards et al., 2025; Faux & Perry, 1999).

This study evaluates how groundwater conservation policies—specifically curtailments that reduce the maximum legally permitted groundwater pumping—are reflected in the value of irrigated cropland in Kansas. Groundwater depletion is often characterized as a common-pool resource problem, where individual extraction decisions impose external costs on other users and contribute to resource decline (Ostrom, 1999). Policies that further restrict the maximum legally permitted level of groundwater extraction create competing forces for landowners. On one hand, curtailments can benefit landowners by mitigating common-pool losses that arise when uncoordinated individual pumping depletes the shared aquifer (Edwards, 2016). On the other hand, binding constraints on water use directly reduce pumping flexibility and imply negative welfare impacts on those whose extraction is curtailed (Earnhart & Hendricks, 2023; Edwards et al., 2025). As a result, the net effect of groundwater

regulation on land values is ambiguous: reduced water access may lower current agricultural returns, while improved long-term resource conditions may increase the expected future value of irrigation.

Using a hedonic pricing framework, this paper examines how regulatory limits on groundwater use are capitalized into observed land transactions in two Kansas policy areas: the Sheridan 6 Local Enhanced Management Area (LEMA) and the Walnut Creek Intensive Groundwater Use Control Area (IGUCA). A key contribution 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. However, irrigated agricultural land trades relatively infrequently, and conservation policy areas in Kansas are geographically limited. As a result, the number of pre- and post-policy observations within treated areas is small, which limits the precision of estimated effects. To complement the hedonic analysis, we also implement a matched-transaction comparison of land sales inside and outside the LEMA.

The results are suggestive but not definitive. Level models consistently show a positive association between LEMA location and land values, with fully treated transactions associated with values approximately 20-22% higher than comparable control transactions, though this premium likely reflects pre-existing land quality differences rather than a policy-induced effect. For the IGUCA, difference-in-differences estimates suggest that policy implementation is associated with land values approximately 32% lower for fully treated transactions relative to controls. This estimate, however, is based on a limited pre-policy sample and should be interpreted cautiously. Taken together, the results indicate that the two policies are associated with markedly different land market outcomes, consistent with differences in regulatory design and local agricultural conditions. However, the small number of treated transactions limits statistical precision, and larger samples would be required to draw stronger causal conclusions.

2. Background

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

2.1 Water Policy in Kansas

Prior to 1945, Kansas water law followed common law doctrines similar to those in eastern U.S. states, under which water rights were tied to land ownership adjacent to a water source (i.e., riparian rights). In the case of groundwater, this framework effectively allowed landowners to extract water beneath their property with few legal constraints (Griggs, 2014; Peck, 2013). However, this common law approach proved increasingly inadequate in Kansas as the expansion of irrigation and the adoption of technologies such as center pivot systems accelerated groundwater extraction (Peck, 2005). The limits of the common law system were formally recognized by the Kansas Supreme Court in *State ex rel. Peterson v. Kansas State Board of Agriculture* (1944), which underscored the Chief Engineer's lack of authority to regulate water use. The *Peterson* decision directly prompted legislative reforms that restructured how water rights are defined and administered in the state.

Responding to the shortcomings of common law doctrines, the Kansas Legislature enacted the 1945 Kansas Water Appropriation Act (KWAA). The KWAA established the prior appropriation doctrine—"first in time, first in right"—under which the first user to put water to a beneficial use holds the senior claim to that water (Peck, 2005). This framework fundamentally redefined water rights in Kansas by establishing that all water within the state is dedicated to public use. Under this system, landowners do not own the water itself; instead, they hold usufruct rights that allow them to use water for beneficial purposes, subject to state regulation.

Under Kansas's prior appropriation system, water rights are administered by the Division of Water Resources (DWR) and are defined as both appurtenant to and severable from land (K.S.A. 82a-701(g)). Appurtenance means that a water right is tied to the location where water is applied and typically transfers with the land when it is sold. At the same time, water rights are severable, meaning they can be transferred to different locations or uses, subject to regulatory approval. By treating water rights as transferable property interests, the 1945 legislation effectively established them as legally protected, tradable assets that can be bought, sold, and reallocated across uses and locations, subject to regulatory approval. In practice, however, such transfers are relatively uncommon due to regulatory oversight, administrative burden, and approval criteria.

2.2 Groundwater Management Districts & Curtailment Mechanisms

The rapid expansion of irrigated agriculture across western Kansas accelerated declines in the High Plains Aquifer through the late 1960s, prompting the Kansas Legislature to adopt new tools for addressing region-specific

water management challenges (Peck, 2005). This effort culminated in the passage of the Groundwater Management District (GMD) Act in 1972. The GMD Act created a decentralized framework that gave local water users greater authority over groundwater management while maintaining the state's underlying prior appropriation system. GMDs are local governing bodies led by elected boards of landowners and water users, allowing management decisions to reflect local conditions. A key feature of this framework is the authority to implement "basin closures," which restrict the issuance of new groundwater permits in designated areas, subject to approval by the Chief Engineer of the DWR. Basin closures strengthened the connection between state-level water law and local management, enabling more tailored responses to groundwater depletion across western Kansas.

To address growing water use conflicts and accelerating groundwater declines, the Kansas Legislature amended the GMD Act in 1978 to introduce Intensive Groundwater Use Control Areas (IGUCAs) as an additional management tool. The IGUCA provision gives the Chief Engineer of the DWR authority to impose corrective controls in areas experiencing significant groundwater depletion. As a primarily top-down regulatory mechanism, IGUCAs allow the DWR to curtail groundwater allocations, typically guided by considerations such as water right seniority (K.S.A. 82a-1038(b2)). In contrast, Local Enhanced Management Areas (LEMAs), introduced in 2012, represent a more bottom-up approach to groundwater management. Rather than being imposed by the state, LEMAs are initiated by GMDs and developed with input from local stakeholders. These plans establish locally defined conservation goals and management practices, subject to approval by the DWR (K.S.A. 82a-1041).

This 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 established in 1992 by the Chief Engineer after the Division of Water Resources determined that groundwater withdrawals by local irrigators were reducing surface water flows to the Cheyenne Bottoms Wildlife Area within the Walnut Creek drainage basin (DWR, 2009). The agency also concluded that total withdrawals exceeded natural recharge rates. Protecting Cheyenne Bottoms was a central objective of the IGUCA, in part because the Kansas Department of Wildlife & Parks holds a vested surface water right in Walnut Creek.[2] The Sheridan 6 LEMA was established in 2012 by Groundwater Management District No. 4 with the objective of extending aquifer life by reducing the rate of groundwater depletion (Golden, 2018). Both policies reduce allowable groundwater allocations within their respective boundaries. However, the mechanisms differ in important

[2] Vested rights are a type of right established through use before state water appropriation laws were put in place.

ways. The Walnut Creek IGUCA curtails allocations based on water right seniority, with junior rights receiving larger reductions than senior rights (Earnhart & Hendricks, 2023; Edwards et al., 2025). In contrast, allocations under the Sheridan 6 LEMA are reduced uniformly across irrigators on the basis of historic useage, regardless of seniority (Drysdale & Hendricks, 2018). Despite these differences in design, both policies reduced aggregate groundwater use by approximately 20% relative to historical levels.

3. Data

The study utilizes data from multiple sources. Table 1 presents summary statistics for transactions inside and outside the policy areas. The rest of Section 3 details each source of data.

3.1 Transaction-level Sales Data

This analysis utilizes transaction-level sales data for every agricultural land transaction in 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 PVD data provides transaction value, transaction date, acreage by land use (e.g., grassland, cropland), and appraised value of improvements. The analysis is restricted to transactions within counties surrounding the Walnut Creek IGUCA and the Sheridan 6 LEMA having irrigated acres. The counties included are Ness, Rush, and Barton surrounding the Walnut Creek IGUCA and Thomas and Sheridan surrounding the Sheridan 6 LEMA (Fig. 1). Transactions are dropped if they have total acreage greater than 5,000 acres or have total appraised values of improvements greater than $100,000.[3] Transactions are also restricted to arms-length to ensure accurate reflections of fair market values. Arms-length transactions are determined using validity codes in the sales data. These restrictions leave 515 observable transactions, including 5 transactions within the Sheridan 6 LEMA after the policy enactment and 38 transactions 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

[3] A potential concern is irrigation capital (e.g., center pivots) appraised into improvements. However, Edwards et al. (2025) find no evidence of irrigated and non-irrigated transactions having systematically different improvements in western Kansas.

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 proportions of clay, silt, and sand composition, the organic matter content in the soil, and the slope. These attributes together control for the productivity of soil.

3.3 Climate Data

Climate data is obtained from the PRISM Group (https://prism.oregonstate.edu/). We compute three weather variables: number of degree days between 10C and 32C, number of degree days above 32C, and precipitation. 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.

3.4 Parcel Boundaries

The PVD transaction data do not include precise parcel geolocations. To address this limitation, we obtain parcel boundary polygons from Regrid, which include a unique parcel identification number. We use these identifiers to link transaction records in the PVD data to their corresponding spatial locations. We then overlay the resulting parcel geolocations with the boundaries of the Walnut Creek IGUCA and Sheridan 6 LEMA to calculate the share of each transacted parcel that overlaps with the respective policy areas. This allows us to measure the extent of policy exposure at the transaction level based on acreage overlap.

4. Methods

The primary strategy is a hedonic regression that estimates the effects of the Walnut Creek IGUCA and the Sheridan 6 LEMA on land prices while controlling for soil, land, and climate characteristics. We first present area-specific descriptive statistics and mean comparison tests to characterize differences between transactions inside and outside the policy areas. We then supplement the regression analysis with a matched-transaction comparison as a case-study approach, focusing on the Sheridan 6 LEMA to provide additional evidence on its association with land values.

4.1 Descriptive Statistics

Table 1 presents descriptive statistics and mean comparisons for land transactions located inside and outside the Sheridan 6 LEMA and the Walnut Creek IGUCA. The control group consists of transactions from counties

surrounding the policy areas (Sheridan and Thomas for the LEMA; Barton, Ness, and Rush for the IGUCA). Reported differences are obtained from regressions of each variable on an indicator for policy-area location, controlling for county fixed effects and quadratic year trends. These comparisons are descriptive in nature and should not be interpreted as causal effects of policy designation. Instead, they characterize how transactions inside and outside the policy boundaries differ on average in terms of land values, land use, climate, and soil attributes.

4.1.1 Sheridan 6 LEMA

Within the LEMA, transactions inside and outside the boundary differ along several dimensions after controlling for county and year effects. Land prices are significantly higher within the LEMA, with transactions averaging approximately $593 per acre more than comparable controls. Land use patterns also differ: the share of irrigated land is higher inside the LEMA (+0.074, marginally significant), while grassland shares are lower (−0.051, marginally significant). Dryland cropping shares and transaction size do not differ significantly.

Climate and soil characteristics exhibit systematic differences. Transactions within the LEMA occur in areas with lower precipitation (−0.949 inches, significant) and greater exposure to both moderate and extreme heat (all significant). Soil texture differences are modest but consistent: parcels inside the LEMA have higher silt content (+1.496 percentage points, significant), lower sand content (−1.871 percentage points, significant), and substantially higher soil organic carbon (+3.924 kg/m², significant), while clay content does not differ significantly. Slope is slightly lower within the LEMA (−1.124 percentage points, significant).

Overall, transactions inside the LEMA are associated with more irrigated land, higher soil quality, greater heat exposure, and slightly lower precipitation, with land values remaining meaningfully higher after accounting for county and year effects.

4.1.2 Walnut Creek IGUCA

Transactions inside the IGUCA differ from those outside along several dimensions, though relatively few differences remain statistically significant after accounting for county and year trends. Land values are lower inside the IGUCA ($1,771 vs. $2,563), but this difference decreases to approximately −$306 and is not statistically significant once controls are included. Similarly, irrigated shares are lower inside the IGUCA (0.529 vs. 0.609) and grassland shares are higher (0.161 vs. 0.060), but these differences are not statistically significant after controlling for county

and year trends. Dryland cropping shares and transaction size also do not differ meaningfully between the two groups.

Climate conditions inside and outside the IGUCA are broadly similar — differences in precipitation and heat exposure are small and not statistically significant. Soil characteristics exhibit the largest differences: IGUCA transactions inside the boundary have substantially higher silt content (+21.1 pp, significant) and clay content (+9.0 pp, significant), much lower sand content (-30.1 pp, significant), and significantly higher soil organic carbon (+3.812 kg/m², significant). Slope differences are small and not statistically significant.

Overall, the most substantial differences for IGUCA transactions are in soil characteristics, while apparent differences in land values and irrigation status are not statistically significant after accounting for county and year trends. As with the LEMA, these patterns reflect underlying spatial sorting of land characteristics rather than causal effects of IGUCA designation.

4.2 Transaction Timing and Trends

Figure 2 plots the temporal distribution of land transactions within each policy area, providing context on market activity surrounding policy adoption. There are 45 observed transactions within the IGUCA and 31 within the LEMA. However, transactions are unevenly distributed over time, with particularly limited observations in key periods for identification. Only seven transactions occur within the IGUCA prior to the 1992 policy enactment, while just five transactions are observed within the LEMA after the 2012 policy enactment. These gaps highlight the thin pre-policy support for the IGUCA and limited post-policy support for the LEMA.

Figure 3 presents corresponding trends in log land prices for treated and control transactions and provides visual support for a difference-in-differences (DiD) approach. To address the infrequency of transactions, values are aggregated into three-year bins to smooth the price series. In the IGUCA setting (Panel A), treated prices appear below control prices prior to 1992, though with only seven pre-policy transactions the pre-trend is estimated very imprecisely and should be interpreted with considerable caution. After enactment, treated prices rise gradually while controls exhibit a sharp spike around 2001 before declining, but again the limited number of observations makes it difficult to draw firm conclusions about post-policy dynamics. In the LEMA setting (Panel B), treated and control prices both rise steadily prior to 2012, offering some visual support for parallel pre-treatment trends, though the post-policy period is represented by only five treated transactions. With so few post-policy observations, the

apparent convergence of treated and control prices after enactment is suggestive at best. Taken together, the figures are broadly consistent with a DiD framework but the thin transaction counts — particularly pre-policy in the IGUCA and post-policy in the LEMA — mean that visual trend comparisons carry limited evidentiary weight, and estimated effects should be interpreted with corresponding caution.

4.3 Matched-Transaction Comparison

Unlike the Walnut Creek IGUCA, which has 38 post-policy transactions, the Sheridan 6 LEMA has only five, limiting the statistical power of hedonic regressions to precisely estimate policy effects. To complement the regression analysis, a matched parcel comparison is conducted.

This approach identifies transactions within the Sheridan 6 LEMA and matches each to similar transactions outside the policy boundary but within comparable market, soil, and aquifer conditions. Matches are selected using four criteria. First, geographic proximity: the comparison transaction must be located within GMD 4. Second, land use similarity: irrigated acreage shares must be within ±5 percentage points. Third, soil composition: clay, silt, and sand shares must each fall within ±7.5 percentage points. Fourth, timing: transactions must occur within ±3 years of the LEMA sale.

These criteria ensure that matched transactions are similar in land use, soil productivity, and local market conditions, while differing primarily in exposure to the groundwater restriction policy. Comparing real price per acre between LEMA transactions and their matched counterparts provides transaction-level evidence of how groundwater restrictions are capitalized into land values and serves as a complement to the regression-based analysis.

4.4 Hedonic Price Model

Land values are modeled using a hedonic pricing framework, which conceptualizes the value of transaction i as a function of its characteristics (Rosen, 1974). In competitive land markets, agricultural land prices reflect the present discounted value of expected current and future land rents (Plantinga & Miller, 2001). Attributes desired by land market participants will be bid up, while undesirable attributes will be bid down. The hedonic price function includes three categories of transaction attributes: exposure to water curtailment policies (z^p), land and soil characteristics (z^s), and climate variables (z^w). Together, these attributes determine the observed market price of

transaction i. The central question of this study is whether groundwater curtailments are capitalized into higher, lower, or unchanged land values.

We specify a semi-log functional form when estimating the contribution of each component to land value, as transaction prices are strictly positive. Regression coefficients are therefore interpreted as the proportional change in price per acre associated with a marginal change in each covariate. The first estimating equation associates policy area location with land values without decomposing effects into pre- and post-policy periods:

$$\ln\left(\frac{price}{acre}\right)_{it} = \Gamma_r' z_{it}^{p} + \Gamma_s' z_{it}^{s} + \Gamma_c' z_{it}^{w} + \delta_1 t + \delta_2 t^2 + \mu_c + \epsilon_{it} \quad (1)$$

The terms Γ_r, Γ_s, and Γ_c are vectors of parameters to be estimated pertaining to curtailment effects, land and soil characteristics, and climate characteristics, respectively. Quadratic year trends are included to control for gradual changes in land values over time (e.g., macroeconomic conditions). County effects, μ_c, are included to capture temporally stable differences in land factors across counties. The error term, ϵ_{it}, captures variation not explained by the independent variables.

Four models are estimated using equation (1), differing in their treatment definitions and geographic scope. In all models, treatment intensity is measured continuously as the proportion of transaction acreage located within the policy boundary. This approach accommodates transactions that straddle policy boundaries and makes use of variation in the degree of exposure to groundwater curtailment. Standard errors are bootstrapped using 999 replications throughout to account for the small number of transactions in key periods.

Model 1 pools all transactions and includes a single continuous treatment measure equal to the proportion of transaction acreage located within either the Sheridan 6 LEMA or the Walnut Creek IGUCA. Model 2 also pools all transactions but separates the treatment into two continuous measures — one for each policy area — allowing the LEMA and IGUCA to have differential effects on land values. In both Models 1 and 2, the control group consists of all transactions with no acreage inside either policy boundary and serves as the counterfactual, representing expected land values in the absence of curtailments. Models 3 and 4 restrict the sample geographically to improve comparability between treated and control transactions. Model 3 includes only transactions in Thomas and Sheridan counties, in the vicinity of the LEMA, while Model 4 includes only transactions in Barton, Rush, and Ness counties, in the vicinity of the IGUCA. Together, the four models allow for estimation of both pooled and region-specific effects of

groundwater regulation, with the geographically restricted models providing a more local comparison between treated and control transactions by limiting the influence of regional price differences unrelated to groundwater policy.

The second estimating equation extends equation (1) by decomposing the treatment variable into pre- and post-policy periods, allowing for a difference-in-differences (DiD) identification strategy. Rather than estimating the average level difference between inside and outside transactions, the DiD framework isolates the change in land values following policy enactment relative to the trajectory of control transactions over the same period:

$$\ln\left(\frac{price}{acre}\right)_{it} = \beta_1(T_{it} \times Post_{it}) + \beta_2 T_{it} + \beta_3 Post_{it} + \Gamma_s' z_{it}^s + \Gamma_c' z_{it}^w + \delta_1 t + \delta_2 t^2 + \mu_c + \epsilon_{it} \quad (1)$$

where T_{it} is the continuous treatment intensity measure and $Post_{it}$ is an indicator equal to one for transactions occurring after policy enactment. The interaction, $(T_{it} \times Post_{it})$, is the DiD estimator of interest, with coefficient β_1 capturing the differential change in log price per acre associated with a unit increased in treated acreage share following policy enactment. The coefficient β_2 captures any preexisting differences between treated and untreated transactions. The coefficient β_3 captures post-policy enactment temporal effects common to all transactions. Note that separate treatment measures and post-policy indicators are included for the LEMA and IGUCA in pooled models, yielding policy-specific estimates β_1^{LEMA} and β_1^{IGUCA}.

As with equation (1), treatment intensity is measured continuously as the proportion of transaction acreage located within the policy boundary, and standard errors are bootstrapped using 999 replications throughout. Three specifications are estimated using equation (2). Model 5 pools all transactions and includes separate continuous treatment measures for the LEMA and IGUCA, each interacted with their respective post-policy indicators. This allows the pre-to-post change in land values to differ across the two policy contexts while drawing on a common control group of transactions with no acreage inside either policy boundary. The identifying assumption is that, in the absence of regulation, treated and control land values would have followed parallel trends over time. Models 6 and 7 estimate the DiD within geographically restricted samples, mirroring the structure of Models 3 and 4 in equation (1). Model 6 includes only transactions in Thomas and Sheridan counties, while Model 7 includes only transactions in Barton, Rush, and Ness counties. These locally restricted specifications reduce the risk that the control group reflects systematically different market conditions and provides a more credible local counterfactual for each policy area. Given the limited number of post-policy transactions in the LEMA and pre-policy transactions in the IGUCA, all three

DiD models should be interpreted with caution, as statistical precision is constrained by thin transaction counts in key periods.

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 regression results (equation (1)) 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 Comparison

Table 4 reports the characteristics of each Sheridan 6 LEMA transaction alongside summary statistics for their matched comparison transactions. Transaction identifiers are used only for reference. The matching procedure identifies between 2 and 10 comparable transactions per LEMA sale based on the criteria in Section 4.3. Transactions 3, 4, and 5 share overlapping matched sets due to similar land characteristics and sale timing.

Transaction 1 (April 2020; 155.1 acres) includes 57% irrigated and 43% dryland acreage. It yields only two matches, largely because its irrigated share falls below the typical range (~65%) within the geographic and temporal window. The LEMA parcel sold for $4,914 per acre versus $5,207 for its matches, a 6% discount.

Transaction 2 (June 2021; 311.7 acres) has the lowest irrigated share (38%), with the remainder in dryland (57%) and grassland (5%). Three matches are identified. The parcel sold for $3,293 per acre compared to $3,061 for its matches, a 7.1% premium. However, this transaction includes $18,000 in improvements, suggesting the premium may partly reflect capitalized improvements rather than land value alone.

Transaction 3 (March 2023; 312 acres) has a high irrigated land share (77%) and five matched transactions. It sold for $6,957 per acre versus $5,609 for its matches, a 19.4% premium—the largest in the sample—potentially reflecting competition amongst bidders or unobserved parcel attributes.

Transaction 4 (September 2023; 157.4 acres) has a similar land composition as Transaction 3 (75% irrigated) and shares the same five matches. However, it sold for $5,398 per acre, a 3.9% discount relative to the matched

average. The contrast between Transactions 3 and 4, despite similar land characteristics and sale timing, highlights the importance of transaction-specific factors not entirely captured in the data.

Transaction 5 (March 2022; 312.6 acres) consists of two parcels, one inside and one outside the LEMA, with 80% irrigated acreage. Ten matches are identified. The parcel sold for $4,832 per acre versus $5,567 for its matches, a 15.2% discount. Interpretation is complicated by the split location, as only half the acreage is subject to the policy.

Overall, matched comparisons show mixed price differentials across transactions, with both premiums and discounts observed. This variation suggests that transaction-specific factors and limited sample size complicate clear inference, reinforcing the need to interpret these comparisons as complementary to the regression analysis rather than definitive estimates of policy effects.

5.2 Regression Results

Table 2 presents estimates from equation (1), which associates policy area location with land values without decomposing effects into pre- and post-policy periods. All coefficients have been exponentiated and are interpreted as proportional differences in price per acre. Model 1 pools all transactions and estimates a single treatment effect across both policy areas. The pooled estimate is positive (0.088) but not statistically significant, suggesting that on average transactions with greater acreage share inside a policy boundary are not associated with meaningfully different land values. However, this pooled estimate masks heterogeneity across the two policy contexts.

Model 2 separates the treatment into LEMA- and IGUCA-specific effects. The LEMA coefficient is positive and marginally significant (0.201, $p<0.10$), indicating that a unit increase in the proportion of acreage inside the LEMA is associated with land values approximately 20% higher, while the IGUCA coefficient is negative and not statistically significant (-0.095). The opposing signs suggest that the two policies are associated with different land market outcomes, motivating the geographically restricted models.

Models 3 and 4 restrict the sample to the county vicinity of each policy area. The LEMA estimate in Model 3 increases slightly relative to Model 2 and becomes more precisely estimated (0.219, $p<0.05$), indicating that a fully treated LEMA transaction is associated with land values approximately 22% higher than an equivalent untreated transaction in the same vicinity. The IGUCA estimate in Model 4 remains negative and statistically insignificant (-0.061), consistent with Model 2.

Across all models, land use composition is the strongest predictor of land value. Irrigated transactions are associated with land values approximately 245% higher than equivalent grassland transactions in the pooled models, with a larger premium in the LEMA vicinity (320%) and a smaller but still significant premium in the IGUCA vicinity (123%). Dryland cropland transactions also command a premium over grassland, though smaller in magnitude (roughly 55% in the pooled models) and not statistically significant in the geographically restricted specifications. Transaction size is negatively associated with price per acre in most models, consistent with a per-unit size discount for larger parcels. Higher precipitation is associated with higher land values in the pooled and LEMA models, while exposure to extreme heat (degree days above 34°C) is positively and significantly associated with land values across most specifications — likely reflecting the correlation between heat and irrigation-dependent agricultural productivity in this region. Soil texture coefficients are small, with silt content negatively associated with land values in the pooled and IGUCA models and clay content positively associated in the IGUCA vicinity. Soil organic carbon and slope are not statistically significant in any specification.

Table 3 presents estimates from the DiD specification in equation (2), which decomposes the treatment effect into pre- and post-policy periods. As with Table 2, coefficients are interpreted as proportional differences in price per acre. The DiD estimator of interest is the interaction between treatment intensity and the post-policy indicator, which captures the change in land values following policy enactment for treated transactions relative to the counterfactual trend in control transactions.

Model 5 pools all transactions and estimates separate DiD effects for the LEMA and IGUCA. Prior to policy enactment, LEMA transactions are associated with land values approximately 21% higher than control transactions, and IGUCA transactions approximately 14% higher, though neither pre-policy level difference is statistically significant. The post-policy indicators suggest broadly rising land values in the post-period for both areas, though again imprecisely estimated. The DiD estimate for the LEMA is small and positive (0.025) while the IGUCA DiD estimate is negative (-0.230), but neither is statistically significant in the pooled model.

Models 2 and 3 restrict the sample to the county vicinity of each policy area. In Model 2, the LEMA DiD estimate remains small and negative (-0.052) and is not statistically significant, providing little evidence of a meaningful change in land values following LEMA. In Model 3, the IGUCA DiD estimate is negative and statistically significant (-0.324, $p<0.05$), indicating that transactions having 100% of their acreage inside the IGUCA experienced

land values approximately 32% lower following policy enactment relative to control transactions in the same vicinity. This is the only statistically significant DiD estimate across the three models.

The pattern of covariate estimates in Table 3 is broadly consistent with Table 2. Irrigated transactions command large premiums over grassland transactions across all specifications — approximately 249% in the pooled model, 326% in the LEMA vicinity, and 120% in the IGUCA vicinity. Dryland cropland transactions also carry a positive premium over grassland of approximately 55% in the pooled model, though this is not significant in the geographically restricted specifications. Transaction size is negatively associated with land values in the pooled model but not in the restricted samples. Precipitation remains positively associated with land values in the pooled and LEMA models but not in the IGUCA vicinity. Soil texture coefficients follow a similar pattern to Table 2, with silt negatively associated with land values in the pooled and IGUCA models and clay positively associated in the IGUCA vicinity, both statistically significant. Extreme heat exposure, soil organic carbon, and slope are not statistically significant in any DiD specification.

6. Discussion and Conclusion

Taken together, the estimates across Tables 2 and 3 present a mixed and inconclusive picture of how groundwater regulation is reflected in land values. For the LEMA, level models consistently indicate a positive association between policy area location and land values, with fully treated transactions priced approximately 20–22% higher than controls. However, the difference-in-differences estimates do not support a causal interpretation of this premium. The LEMA DiD estimates are small, inconsistent in sign, and statistically insignificant, suggesting that the observed price differential is more likely driven by pre-existing land characteristics than by the policy itself. This interpretation is consistent with the balance table results, which show that LEMA transactions occur on more irrigated and higher-quality land.

For the IGUCA, level models show no meaningful association between policy location and land values, while the geographically restricted DiD specification suggests a large negative effect of approximately 32% following enactment. However, this estimate is based on a very limited pre-policy sample and should be interpreted with caution. The small number of treated transactions—particularly in the IGUCA pre-period and LEMA post-period—limits statistical precision and weakens the credibility of the identifying assumptions of the DiD.

Despite these limitations, the contrasting patterns across the two policies are informative. The negative capitalization observed for the IGUCA is consistent with a top-down regulatory approach that imposes binding constraints on groundwater use to achieve environmental objectives, specifically preserving water flows to the Cheyenne Bottoms wildlife area, rather than sustaining agricultural production. In contrast, the absence of a detectable effect for the LEMA suggests that locally managed conservation policies, which are designed with producer input and long-run irrigation viability in mind, may not generate clear or consistent price signals in land markets.

The matched-transaction analysis reinforces this interpretation. Price comparisons for the five LEMA transactions reveal substantial heterogeneity, with no consistent pattern of premiums or discounts relative to matched controls. This lack of systematic direction further supports the conclusion that the LEMA's effect on land values is not clearly positive or negative.

Overall, the evidence is suggestive rather than conclusive. Thin transaction counts in key periods make the estimates sensitive to individual observations and subject to considerable uncertainty. While the results point to meaningful differences in how alternative groundwater policies are reflected in land markets, larger samples of treated transactions would be required to draw firm causal conclusions.

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Tables and Figures

Table 1. Mean values for transactions inside and outside the curtailment areas.

	LEMA			IGUCA		
	Outside	Inside	Difference	Outside	Inside	Difference
Price per acre	2,445.777	2,728.302	592.618**	2,562.587	1,771.268	-305.650
Proportion irrigated	0.653	0.671	0.074*	0.609	0.529	0.038
Proportion dry cropland	0.285	0.259	-0.023	0.331	0.310	-0.062
Proportion grass	0.062	0.070	-0.051*	0.060	0.161	0.025
Total transaction acres	318.274	268.133	-0.660	217.550	209.724	0.443
Average precipitation (inches)	18.511	17.566	-0.949***	22.522	22.327	0.538
Average degree days 10-34C (100s)	19.814	20.786	0.311***	23.543	22.789	-0.093
Average degree days > 34C	11.522	14.931	2.070***	19.717	19.834	-1.002
Silt (%)	63.882	62.756	1.496**	33.918	62.890	21.146***
Clay (%)	22.001	23.556	0.374	20.219	26.890	9.002***
Sand (%)	14.116	13.688	-1.871***	45.863	10.220	-30.148***
Soil organic carbon (kg/m2)	10.024	13.207	3.924***	10.095	16.049	3.812***
Slope (%)	2.397	2.873	-1.124**	1.495	1.399	0.071
N	363	31		84	45	

Note: The LEMA columns summarize information for transactions in Sheridan and Thomas counties. The IGUCA columns summarize information for transactions in Barton, Ness, and Rush counties. The Diff column is the coefficient of a regression of the variable on treatment status, with county fixed effects and quadratic year trends. Standard errors are bootstrapped using 999 replications.

*** p<0.01, ** p<0.05, * p<0.10

Table 2. Regression results for level models.

Variable	(1)	(2)	(3)	(4)
LEMA and IGUCA	0.088			
	(0.074)			
LEMA		0.201*	0.219**	
		(0.097)	(0.100)	
IGUCA		-0.095		-0.061
		(0.107)		(0.126)
Proportion irrigated	2.450***	2.402***	3.219***	1.227**
	(0.199)	(0.200)	(0.259)	(0.370)
Proportion dry cropland	0.549**	0.512*	0.587	0.271
	(0.219)	(0.219)	(0.297)	(0.334)
Total acreage (100s acres)	-0.029**	-0.029**	-0.022*	-0.041
	(0.012)	(0.012)	(0.012)	(0.027)
Average precipitation	0.050***	0.051***	0.063***	0.048
	(0.013)	(0.013)	(0.016)	(0.034)
Degree days 10 - 34C	-0.045	-0.045	-0.096	0.079
	(0.046)	(0.046)	(0.068)	(0.128)
Degree days > 34C	0.021***	0.021***	0.028*	0.015*
	(0.007)	(0.007)	(0.014)	(0.009)
Silt content of soil	-0.007**	-0.005*	0.004	-0.012**
	(0.003)	(0.003)	(0.011)	(0.005)
Clay content of soil	0.007	0.008	-0.004	0.020**
	(0.006)	(0.006)	(0.020)	(0.008)
Soil organic carbon in soil	0.001	0.000	0.005	0.002
	(0.010)	(0.010)	(0.012)	(0.020)
Slope	-0.022	-0.019	0.009	-0.035
	(0.020)	(0.021)	(0.024)	(0.060)
Observations	515	515	387	128

Note: Column 1 aggregates the LEMA and IGUCA policy effects. Column 2 estimates separate LEMA and IGUCA policy effects. Column 3 restricts the analysis to Sheridan and Thomas counties. Column 4 restricts the analysis to Barton, Ness, and Rush counties. Also controls for county fixed effects and quadratic year trends. Standard errors are bootstrapped using 999 replications.

*** p<0.01, ** p<0.05, * p<0.10

Table 3. Regression results for difference-in-difference models.

Variable	(5)	(6)	(7)
LEMA	0.212	0.238	
	(0.118)	(0.141)	
Post-LEMA	0.220	0.132	
	(0.142)	(0.287)	
LEMA * Post-LEMA	0.025	-0.052	
	(0.187)	(0.223)	
IGUCA	0.135		0.331
	(0.191)		(0.212)
Post-IGUCA	-0.104		0.257
	(0.115)		(0.223)
IGUCA * Post-IGUCA	-0.230		-0.324**
	(0.186)		(0.189)
Proportion irrigated	2.494***	3.264***	1.203**
	(0.197)	(0.215)	(0.383)
Proportion dry cropland	0.546**	0.595	0.244
	(0.216)	(0.325)	(0.354)
Total acreage (100s acres)	-0.029**	-0.022	-0.040
	(0.012)	(0.014)	(0.028)
Average precipitation	0.037**	0.054*	0.044
	(0.017)	(0.031)	(0.041)
Degree days 10 - 34C	-0.039	-0.083	0.109
	(0.051)	(0.101)	(0.144)
Degree days > 34C	0.010	0.021	0.011
	(0.009)	(0.021)	(0.013)
Silt content of soil	-0.005*	0.004	-0.015***
	(0.003)	(0.011)	(0.004)
Clay content of soil	0.008	-0.005	0.022***
	(0.006)	(0.024)	(0.008)
Soil organic carbon in soil	0.001	0.006	0.009
	(0.009)	(0.012)	(0.016)
Slope	-0.018	0.010	-0.042
	(0.021)	(0.027)	(0.069)
Observations	515	387	128

Note: Column 1 estimates separate LEMA and IGUCA policy effects. Column 2 restricts the analysis to Sheridan and Thomas counties. Column 3 restricts the analysis to Barton, Ness, and Rush counties. Also controls for county fixed effects and quadratic year trends. Standard errors are bootstrapped using 999 replications.

*** p<0.01, ** p<0.05, * p<0.10

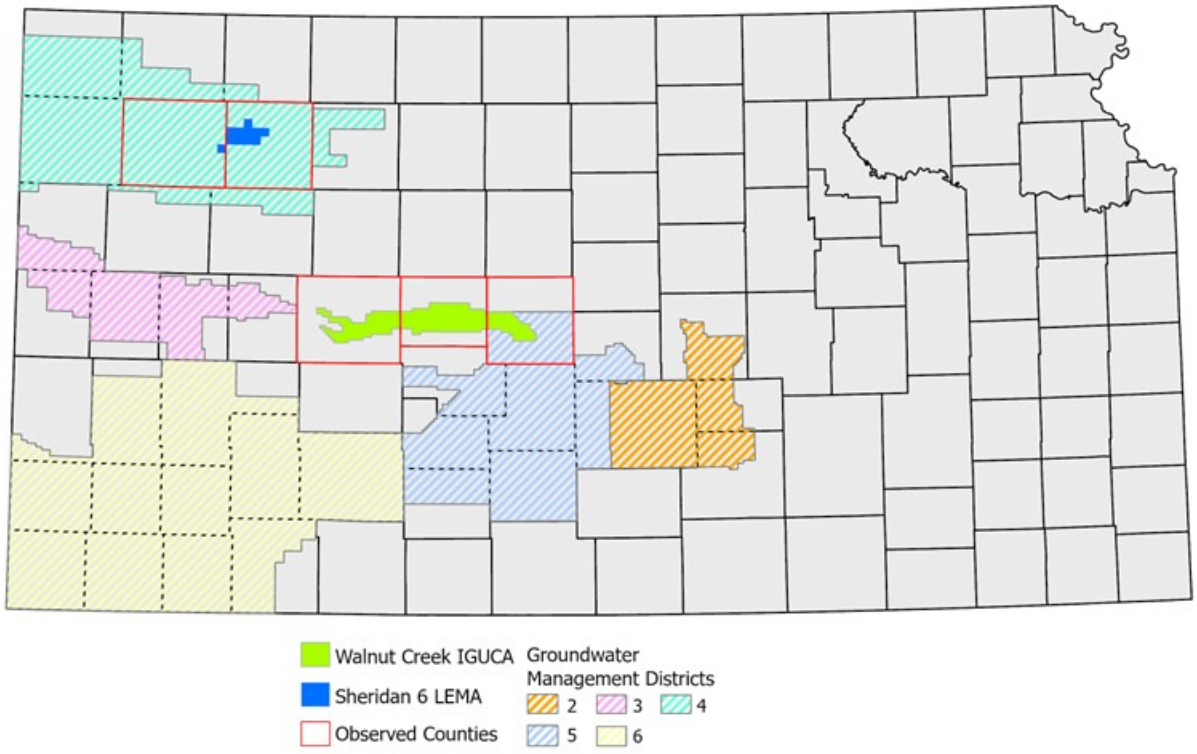

Figure 1. Location of the transaction locations (red counties) and policy areas.

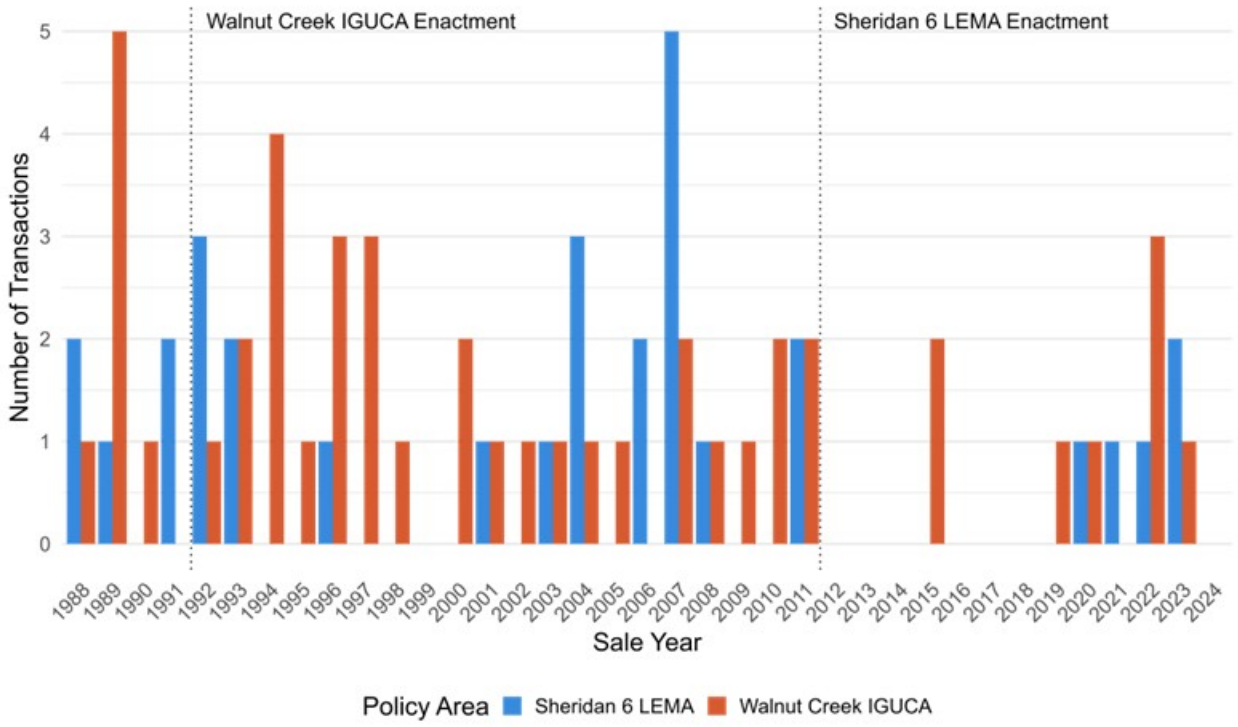

Figure 2. Timing of transactions within the policy areas relative to the policy enactment dates.

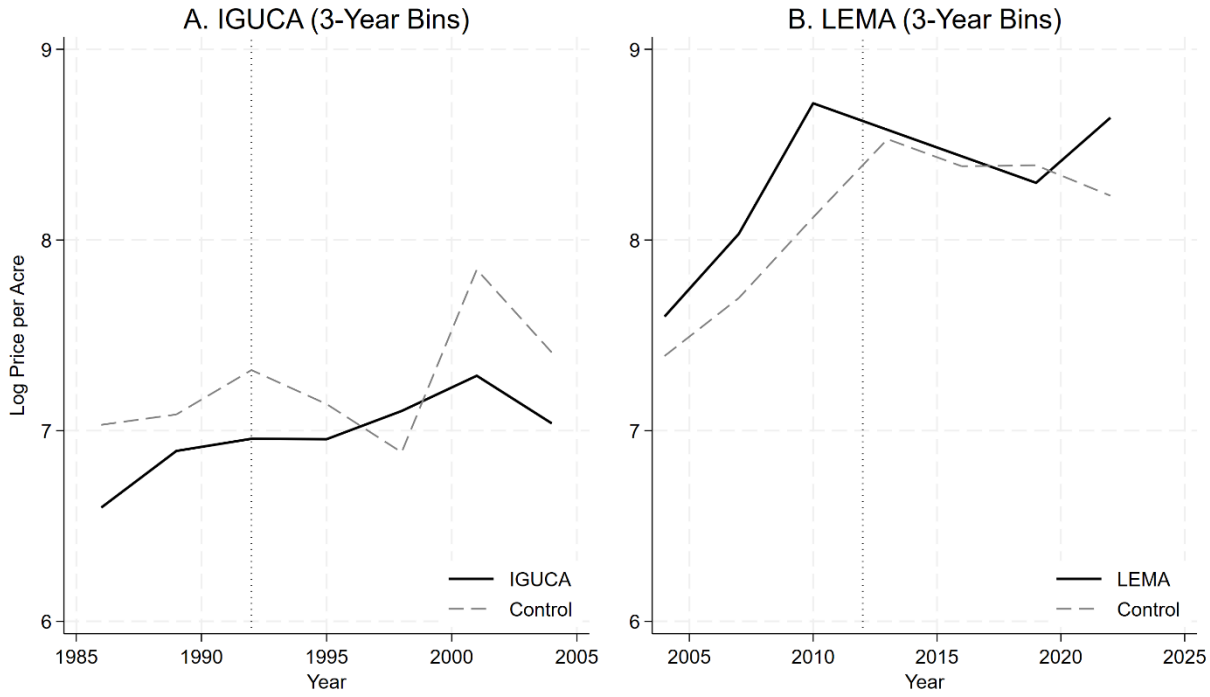

Figure 3. Smooth trends in land prices for treated and control transactions. Panel A shows the IGUCA, enacted in 1992, using transactions from Barton, Ness, and Rush counties. Panel B shows the LEMA, enacted in 2012, using transactions from Thomas and Sheridan counties. Values are aggregated into three-year bins to reduce noise from sparse transaction data. Vertical lines indicate policy enactment dates.