Environmental Change and Land Markets: The Capitalization of Woody Encroachment into Agricultural Land Values

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Abstract

Woody encroachment is a pressing land management challenge in grassland systems, impacting forage production, biodiversity, and ecosystem services. This study combines surveys of landowners and agricultural stakeholders with a hedonic price analysis of agricultural land sales and satellite-derived woody cover in Kansas to assess the economic implications of woody encroachment. Survey results indicate that high control costs, labor constraints, and difficulties prioritizing treatment areas are leading challenges to controlling woody encroachment. We find that participation in training and financial assistance programs is low, largely due to limited awareness, uncertainty about eligibility, and program complexity. Hedonic price model results show that increases in woody cover are associated with higher agricultural land values, with a one-percentage-point increase corresponding to an increase of $9–$27 per acre. These findings underscore the need for policies that lower control costs, clarify eligibility, and simplify participation.

1. Introduction

Across the Great Plains and other grassland regions, woody plant species are expanding and dominating regions that were once primarily herbaceous vegetation (Twidwell et al. 2013). This process, known as woody encroachment, has reshaped rangeland ecosystems and generated concerns from landowners, conservationists, agricultural producers, and policymakers (Morton et al. 2010). Woody encroachment is linked to reduced livestock production (Anadón et al. 2014), biodiversity (Stanton et al. 2018), and ecosystem services (Sala and Maestre 2014). For agriculturally dependent regions such as the Great Plains, expansion of wood and shrub species can affect the agricultural economy by reducing forage production.

Previous studies have documented the ecological causes and effects of woody encroachment (Ding and Eldridge 2024; Soubry and Guo 2022), but relatively little research has examined its economic impacts on agricultural land markets. Existing work largely finds that tree cover provides amenity value in urban and suburban areas (Kovacs et al. 2022 reviews the literature), with some studies also exploring how natural amenities affect agricultural land values more broadly (Bastian et al. 2002; Uematsu, Khanal, and Mishra 2013). For example, Borchers et al. (2014) use USDA June Area Survey data to show that nearby tree cover increases pastureland values, possibly because it supports wildlife habitat and alternative income sources such as hunting leases. Whether woody encroachment directly on the agricultural parcel lowers land values through reduced forage or raises land values through non-agricultural income remains an open empirical question.

This paper investigates how woody encroachment affects agricultural land values across a mix of grassland and cropland in Kansas, a region that has experienced rapid increases in woody cover over the last three decades (see Figures 1 and 2). We first contextualize our hedonic price analysis by presenting data collected from surveys of landowners, farm managers, and rural land appraisers. These surveys capture perceptions of woody encroachment severity and the main challenges to its management. We then estimate a hedonic price model using transaction-level land sales data combined with satellite-derived measures of woody cover to detect how woody cover is capitalized into agricultural land values. This study contributes directly to ongoing discussions of woody encroachment and to the broader literature linking environmental transformations (i.e., expanding woody cover) to economic outcomes (i.e., agricultural land values).

Survey results indicate that woody encroachment is widely perceived as a pressing problem by landowners and stakeholders. However, fewer than one-third of our survey respondents were aware of any funding programs available to help cover control costs, despite substantial public investment into financial and technical assistance programs.[1] A similarly low proportion of respondents had worked with the Natural Resources Conservation Service (NRCS) to restore their land. The main barriers to participating in NRCS programs were lack of awareness and uncertainty about eligibility. Survey respondents consistently reported that limited labor, high costs, and difficulty deciding where to focus control efforts were amongst the top factors contributing to woody encroachment management challenges.

Results from the hedonic price model provide evidence that increases in woody vegetation in Kansas are associated with higher agricultural land values. The average marginal capitalized value of a one percentage point increase in woody cover ranges from about $9/acre to $27/acre (i.e., about 0.6% to 1.9% of average land values). We also find the impact of woody cover on land values is not necessarily linear, with marginal increases in woody cover conferring smaller impacts to land values as the total amount of woody cover increases on the parcel. Our results provide evidence that costly woody control measures may not be wholly incentive compatible in the land market. Strategies to manage woody encroachment—such as mechanical removal and prescribed burning—can impose substantial costs on landowners, yet these investments may not be reflected in higher land values. As a result, landowners may have limited incentives to undertake such costly control efforts. Our results indicate there is clear need for natural resource policies that lower control costs for landowners, provide more transparent eligibility guidelines, and are easy for landowners to navigate.

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 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

[1] NRCS Environmental Quality Incentives Program (EQIP) annual payments in Kansas ranged from $16 million to $29 million from 2008-2024. Approximately $24 million in EQIP payments were obligated to woody encroachment from 2017-2024. (source: unofficial data obtained from contact at Kansas NRCS).

consequential in the Great Plains of the United States, where grasslands underpin 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 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 (Natural Resource Conservation Service 2022), which are outlined in the upper panel of Figure 1. 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.[2] The upper and lower panels of Figure 1 illustrate the spatial extent and severity of woody cover in Kansas in 1988 and 2024 using data obtained through the Rangeland Analysis Platform (RAP).[3] Figure 2 illustrates the change in woody cover (defined as percentage of land covered by woody species) for each of the four priority regions. Counties located within the four outlined ecoregions in Figure 1 have been targeted by the KGPGI as priority areas and constitute the focus of this study.

Looking at Figures 1 and 2, the Flint Hills, Smoky Hills, and Red Hills ecoregions are observed to have experienced the most prominent increase in woody cover. Woody cover has more than doubled on average in the Flint Hills since roughly 1990. Woody cover in the Red Hills and Smoky Hills has approximately doubled on

[2] Practices eligible for financial assistance under KGPGI include brush management, prescribed burns, firebreaks, prescribed grazing, and woody residue treatment.

[3] 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.

average. Woody cover in the Playa Landscape region remains low on average. However, the Play Landscape has experienced localized encroachment, primarily in the vicinity of the Arkansas River drainage (southwest corner of the ecoregion) where woody cover has increased upwards of 20%. Woody encroachment is a particular concern in this ecoregion due to agricultural 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 also clustered within the southeastern corner (e.g., Barber County) 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 altering habitat conditions for grassland-dependent species (Ratajczak, Nippert, and Collins 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, Dillon 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 2025).

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 (Macaulay 2016; Nickerson et al. 2012; 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 (Doye 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 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 profitable leasing opportunities would be reflected in higher land values (Borchers, Ifft, and Kuethe 2014).

While increasing tree cover can 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 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).

3. Materials and Methods

This study draws on multiple sources of information to evaluate landowner and stakeholder perspectives of woody encroachment and how woody cover influences agricultural land values in Kansas. The survey data provides insights into the perceived severity of woody encroachment, factors affecting the control of woody encroachment, and barriers to participating in agency-funded restoration efforts. The transaction-level data allows for empirical estimation that can quantify the capitalization of woody cover into land values. Together, this data provides 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 1. The workshop and mail surveys shared some questions in common, but the mail survey included a longer list of questions not included in the workshop surveys. The workshop surveys were designed to be completed in a brief amount of time while the respondent was at the workshop.

3.1.1 Workshop Surveys

In-person surveys were administered at seven meetings and workshops between February 2023 and June 2024. The surveys were handed out during presentations and/or were available for pickup at registration tables. The in-person events were attended by a combination of landowners, farmers, ranchers, rural appraisers, and community members and is summarized in Table 1. In total, we obtained 163 returned surveys from these events.

3.1.2 Mail-In Surveys

The mail survey was sent to landowners located across the 33 counties outlined in the priority ecoregions in Figure 1 in late March and early April of 2025. Mailing addresses for landowners in Kansas were obtained from DTN.[4] 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 respondents if the address listed a PO box or apartment number due to concerns that such addresses would be located off-farm, thus contaminating the results with respondents that might not be

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

the primary farm decisionmaker. After dropping these potential respondents, we sampled across the 33 counties outlined in Figure 1 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 rangelands in the vicinity of their operation, and factors perceived to be associated with difficulties in controlling woody encroachment. A total of 622 surveys were returned between April and September of 2025 for a response rate of 21%.[5]

3.2 Empirical Data

This paper draws the data used in the hedonic price analysis from multiple sources at the finest spatial resolution possible. Table 2 presents the summary statistics of the variables used in empirical estimation. The next sections detail each source of data.

3.2.1 Transaction-Level Land Sales

This paper utilizes transaction-level agricultural land sales data for the priority counties of the KGPGI that are 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 from county assessors.

[5] All 622 returned surveys used in the analysis answered at least one question.

We first begin with 89,532 statewide observations, omitting outlier transactions and transactions not coded as arms-length from PVD. We define outlier transactions following the method in Edwards, Hendricks, and Sampson (2025). We also omit transactions having total acreage greater than 5,000 acres or total appraised values of improvements greater than $100,000. Parcel specific values and characteristics are aggregated up to the transaction level for multi parcel transactions. Restricting transactions to the core funding counties of the KGPGI leaves 23,130 transactions. Lastly, we omit transactions listing any irrigated cropland within the transaction (~1,100 transactions) or having less than 25% grassland by area (~7,700 transactions) because we are primarily interested in the impacts to grassland and combined cropland-grassland.[6] Borchers et al. (2014) finds that the impact of woody cover on agricultural land can differ according to whether the land is predominantly cropland or grass. These restrictions leave 12,348 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

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[6] The regression results are robust to changing the cutoff for the minimum proportion of grassland in the transaction.
[7] https://regrid.com

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. Importantly, the RAP data provides high resolution satellite imagery that varies across years, allowing our empirical 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). Note that the 30-meter RAP data does not distinguish between different species. A more highly resolved 10-meter layer is available but only dates back to 2018, which would greatly reduce the temporal span of our hedonic analysis. 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 by woody cover (i.e., ranging from 0% to 100% of the parcel area). This information is then linked to the land transaction data using the 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.[8] 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 of agricultural land (Chen et al. 2023).

3.2.5 Climate

Weather data at the grid-cell level are obtained for Kansas from PRISM.[9] We construct four climate variables from the PRISM data to control for climate impacts on the returns to farming (Fisher et al. 2012): 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 April 1 – September 30. We then compute a water deficit variable as the difference between

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

evapotranspiration and precipitation. Reference evapotranspiration is computed from the PRISM data using the Hargreaves and Samani method (1982). 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 Methods

We model agricultural land values in a hedonic price framework. Rosen (1974) posited that products are composed of a bundle of observable characteristics, with each characteristic conferring an implicit (or "hedonic") price as a component of the overall market price of the product. In the context of this paper, agricultural land parcels having characteristics deemed desirable by land market participants will be bid up in a competitive market. The particular emphasis here is to quantify any premium or discount associated with the amount of woody cover on an agricultural parcel at the time of the transaction.

As outlined above, there are various ways in which woody cover may negatively or positively affect agricultural land values. If the forage losses, wildfire risk, soil moisture, and biodiversity effects dominate, then the presence of woody cover on agricultural land would be expected to confer a discount. Conversely, if the recreational and aesthetic opportunities associated with woody cover dominate, then the presence of woody cover on agricultural land would be expected to confer a premium. It is also possible that the opposing effects are offsetting, resulting in no observable land value impact.

We specify a natural log form of price per acre when estimating the impact of woody cover on agricultural land values. The log form of the dependent variable is common in hedonic price studies (Sirmans, Macpherson, and Zietz 2005) and is appropriate in our context for two reasons. First, agricultural land values are strictly positive. Second, land values can differ widely in relative terms. We estimate the real price per acre for transaction i in year t as:

$$\ln \frac{Price}{Acre}_{it} = f(\mathcal{W}_{it}) + \Gamma'\mathcal{C}_{it} + \Omega'\mathcal{S}_i + \phi'\mathcal{Z}_{it} + \eta_l + \tau_t + \epsilon_{it}. \quad (1)$$

In Equation (1) $\mathcal{C}_{it}$ is a vector of climate characteristics, $\mathcal{S}_i$ is a vector of soils characteristics, and $\mathcal{Z}_{it}$ is a vector of all other time-varying characteristics of the land transaction (e.g., number of parcels in transaction, percent natural grassland, etc.). The terms Γ, Ω, and ϕ are vectors of parameters to be estimated. We examine several different functional forms between the price per acre of transaction i and the amount of woody cover on the parcel(s) at time t comprising transaction i. In particular, we specify linear, quadratic, and restricted cubic spline forms on woody cover. We further allow for different knot placements in the restricted cubic spline functions. Our models therefore range from linear to flexibly non-linear. The non-linear models allow for increasing or decreasing marginal values of woody cover that would not be identified in a simple linear specification.

Spatial dummies at the scale of public land survey system (PLSS) townships (6 miles X 6 miles), η_l, are used to control for unobserved differences in agricultural land values that occur over space but are temporally stable over the study period (e.g., access to towns/processors). Year-level dummies, τ_t, are included to account for unobserved factors associated with returns to agriculture such as interest rates and input/output costs that change over time. We estimate Equation (1) using a generalized linear model with log link function and Poisson family to avoid problems of back-transforming the dependent variable from log values to level values. Lastly, we complete Equation (1) by clustering the standard errors at the year to account for possible spatial correlation in land value shocks.

4. Results

We first document results from the workshop and mail surveys before presenting regression estimates from the hedonic price model in Equation (1).

4.1 Survey Results

Figure 3 presents a summary of survey respondent's stated level of severity of woody encroachment in the pastures around their operation. In short, respondents were asked to rate the severity of tree or brush encroachment. Over 60% of respondents from the workshop surveys indicated the severity of encroachment as a major problem. Less than 5% indicated encroachment as not being a problem. By comparison, respondents from the mail survey indicated lower severity on average. Approximately 41% of respondents from the mail survey indicated encroachment as a major or minor problem while 18% indicated encroachment as not being a problem. Differences across the workshop and mail surveys may be indicative of sample selection bias—individuals may have attended the workshops because they were already concerned about woody encroachment.

Table 3 presents the factors respondents identified as the top three contributors to the difficulty of controlling woody encroachment. Note that there was one factor included in the workshop surveys that was not included in the mail survey for parsimony (ineffective treatments). The last column of Table 3 shows how often respondents identified each factor as one of the top three challenges in controlling woody encroachment. Factors that were selected at high frequency for the mail and workshop surveys include: labor limitations (e.g., availability of crew or equipment to conduct control measures), overall cost of control, and deciding where to prioritize control treatments on the land. Landowners that are absent or otherwise not engaged in stewardship of the land was indicated at high frequency in the mail survey but not in the workshop survey. Landowner aversion to the risks/liability associated with prescribed burns was also indicated by about one-quarter of respondents across both surveys. Lastly, perceptions that woody cover is beneficial to wildlife was indicated by nearly one-half of respondents in the workshop survey, but by only 13% of respondents in the mail survey.

Table 4 summarizes responses to questions in the mail survey focused on agency interactions. Financial and technical assistance to producers is available through programs such as NRCS EQIP and KGPGI. For context, annual EQIP expenditures in Kansas between 2008 and 2024 were as high as $29 million. Less than one-third of respondents indicated awareness of any assistance programs for controlling woody encroachment (Panel A). This result is consistent with prior survey findings showing that many producers lack information about program eligibility or perceive the application process as overly complex (Sampson et al. 2024). Not surprisingly, given the Panel A results, roughly three-quarters of respondents said they had not worked with NRCS on rangeland restoration (Panel B). Among those who had worked with NRCS, about two-thirds reported a positive overall experience, while approximately one-quarter reported a negative experience (Panel C). The most cited barriers to NRCS participation were lack of awareness, uncertainty about eligibility, and limited user friendliness of the programs (Panel D).

4.2 Regression Results

The results of estimating Equation (1) are presented in Table 5. Each variable has been exponentiated so that coefficients can be accurately interpreted as proportional effects. The marginal effect reported at the bottom of Table 5 shows the change in per-acre land value (in $/acre) associated with a one-percentage-point increase in woody cover on a parcel, holding all other variables at their sample means. Columns 1 and 2 of Table 5 specify woody cover linearly and as a quadratic in the regression, respectively. Columns 3 and 4 specify woody cover using restricted cubic splines, with three knots placed at the 10th (0.3%), 50th (1.6%), and 90th (10.0%) percentiles of woody cover observed in transactions (column 3) and four knots placed at the 5th (0.2%), 35th (1.0%), 65th (2.9%) and 95th (14.5%) percentiles of woody cover observed in transactions (column 4). The placement of knots follows the heuristics outlined in Harrell (2015). The restricted cubic spline constrains the relationship to be linear before the first and after the last knot and uses cubic polynomials to fit the relationship between knots.

The variable of most interest, woody cover, is positive and statistically significant in column 1 of Table 5. The coefficient indicates that a one percentage point increase in woody cover confers a 0.6% increase in agricultural land values on average. In terms of the levels, this amounts to about $9/acre.[10] The linear term on woody cover in column 2 of Table 5 is positive and statistically significant while the squared term is negative and statistically significant. In other words, the marginal effect of woody cover diminishes as the total amount of woody cover on parcel(s) in the transaction increases. In terms of levels, the average marginal impact of a one percentage point increase in woody cover is about $16/acre (~1% of average land values) using the joint coefficients in column 2.

Direct interpretation of the coefficients on woody cover in columns 3 and 4 of Table 5 is not straightforward. Instead, we plot the predicted value of the estimated non-linear relationship over a range of woody cover values along with a histogram of woody cover for observed transactions in Figure 4. Accounting for non-linearity using three or four knots in a restricted cubic spline specification gives an estimated average marginal effect from a one percentage point increase in woody cover of about $27/acre and $18/acre, respectively. Similar to the quadratic specification in column 2, the restricted cubic splines indicate diminishing marginal valuations of woody cover. Marginal changes in woody cover once the total amount of woody cover on-parcel exceeds 10% has a small effect on agricultural land values. For instance, using the specification in column 3 of Table 5, the predicted difference in 15% woody cover relative to 10% woody cover is just $27/acre (~2% of average land values). Conversely, the predicted difference in 5% woody cover relative to 1% woody cover is $110/acre (~7.5% of average land values). A similar pattern is observed when we specify four knots in the regression.

[10] Note that the average amount of woody cover across transactions in our study area is about 3.8%, so a one percentage point increase relates to a proportional increase of approximately 26% relative to the average.

The coefficients on the remaining independent variables largely follow according to expectation. The percentage of land that is natural grass or tame grass is interpreted relative to non-irrigated cropland (the omitted land use type). Natural grassland confers a lower market value than non-irrigated cropland. Tame grass (e.g., brome) confers a higher market value than non-irrigated cropland, though the effect is only marginally statistically significant. Degree days in the beneficial temperature window confer a land market premium, while degree days in the harmful degree window confer a land market discount, reflecting higher returns to farming (Fisher et al. 2012). Parcels with more slope confer a land market discount. Sand and silt content in the soil are interpreted relative to clay content (the omitted category)—both sand and silt confer premiums relative to clay. Increased levels of soil organic carbon are associated with higher land values, consistent with the productivity effects of more fertile soil (Ma et al. 2023). Lastly, the per-acre value of the land transaction decreases as the total number of parcels in the transaction increase.

5. Discussion and Conclusion

Woody encroachment is widely recognized as a pressing land management challenge in Kansas. Our survey results indicate that high control costs, labor constraints, and difficulties in prioritizing treatment locations are among the primary challenges to effective rangeland management, suggesting that woody encroachment persists largely because active control is costly and operationally complex. Indeed, many contractors in Kansas bid project costs using labor rates and equipment rates, where the rates can exceed $200/hr.[11] This can translate to $100/acre or more (Renae Blum 2020). Furthermore, while prescribed burning has been shown to be an effective and economical management tool (Scholtz et al. 2018), only about half of respondents reported the practice as common, likely reflecting concerns over legal liability and the logistical challenges (e.g., Weir, Twidwell, and Wonkka 2016) of coordinating a burn. The survey data generally points to low awareness of, and participation in, financial and technical assistance programs designed to restore rangeland, despite substantial public investment in these programs (e.g., EQIP, KGPGI). Most respondents cited lack of awareness, uncertainty about eligibility, or the programs' limited user friendliness as reasons for not participating. This finding is consistent with previous survey evidence related to water conservation programs (e.g., Sampson et al. 2024).

[11] Personal communication with pasture clearing contractors in the Flint Hills and Smoky Hills.

Results from the hedonic price model indicate that increased woody cover is associated with increases in agricultural land values. The value of a one percentage point increase in woody cover on the parcel is associated with increased per-acre value ranging from $9 to $27 depending on model specification. These findings are consistent with those in Borchers et al. (2014) and create somewhat of a management and policy paradox: landowners face high costs to control woody encroachment on grassland, yet the land market places a land value premium on woody cover. Thus, landowners may have weak market incentives to remove brush and trees, especially when control costs are high. This suggests a clear role for policy interventions that substantially lower the costs of control, have clear eligibility guidelines, and are easy to navigate for producers or landowners.

Table 1. Summary of in-person workshop survey events.

Event	Date	Location	Type of attendee
Kansas Society of Farm Managers and Rural Appraisers Winter Meeting	Feb. 15-17, 2023	Hays, KS	Rural appraisers, farm managers
Livestock Learning Roadshow	March 15, 2023	Washington, KS	Farmers, ranchers
Ag Professionals Symposium	Aug. 3-4, 2023	Kansas City, MO	Rural appraisers, farm managers
Kansas State University Risk and Profit Conference	Aug. 17-18, 2023	Manhattan, KS	Farmers, ranchers, landowners
Prescribed Burn Workshop	Feb. 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

Note: 163 total respondents

Table 2. Summary statistics for data used in empirical model.

	n	mean	sd
Price per acre ($2024)	12,348	1,441.18	1,045.59
Woody cover (%)	12,348	3.80	5.66
Proportion of land that is dry cropland	12,348	23.62	26.16
Proportion of land that is natural grass	12,348	72.26	27.88
Proportion of land that is tame grass	12,348	4.12	13.22
Water deficit (inches)	12,348	14.90	7.34
Degree days >34C	12,348	15.15	8.02
Degree days 10 - 34C (100's)	12,348	23.06	1.20
Slope (%)	12,348	5.04	2.67
Sand content (%)	12,348	17.92	16.72
Silt content (%)	12,348	49.40	10.21
Clay content (%)	12,348	32.68	9.32
Soil organic carbon (kg/m^2)	12,348	9.05	2.55
Number of parcels in transaction	12,348	1.60	1.20

Table 3. Top factors contributing most to the difficulty of controlling tree/brush encroachment.

Panel A: Reponses from the mail survey.	n	%
Labor limitations	297	52.2%
Cost of control	244	42.9%
Deciding where to prioritize control treatments	220	38.7%
Absent/unengaged landowners	178	31.3%
Liability/risk/fear of burning	153	26.9%
Other	83	14.6%
Perceptions that tree/brush cover are beneficial to wildlife/ecosystem/etc.	73	12.8%
Past control efforts have been ineffective or had short duration benefit	62	10.9%
Lack of information regarding which control techniques are the most effective/appropriate	56	9.8%
Panel B: Reponses from the workshop surveys.	**n**	**%**
Labor limitations	94	57.7%
Cost of control	85	52.1%
Perceptions that tree/brush cover are beneficial to wildlife/ecosystem/etc.	75	46.0%
Deciding where to prioritize control treatments	63	38.7%
Management is impacted by the actions/inactions of neighboring landowners	45	27.6%
Liability/risk/fear of burning	42	25.8%
Absent/unengaged landowners	30	18.4%
Lack of information regarding which control techniques are the most effective/appropriate	18	11.0%
Ineffective treatment techniques	17	10.4%
Other	7	4.3%

Note: 569 respondents from the mail survey and 163 respondents from the workshop surveys.

Table 4. Awareness, experiences, and barriers to working with NRCS to control woody encroachment.

Panel A: Aware of funding opportunities to control woody vegetation on rangeland?	n	%
Yes	190	31.1%
No	420	68.9%
Panel B: Worked with NRCS to restore and protect rangeland?	**n**	**%**
Yes	163	26.4%
No	454	73.6%
Panel C: Rate of overall experience working with NRCS	**n**	**%**
Positive	109	67.7%
Neutral	15	9.3%
Negative	37	23.0%
Panel D: Main barriers to your participation with NRCS?	**n**	**%**
Lack of awareness of funding opportunities for your operation	228	66.3%
Unsure if your operation is qualified for participation	160	46.5%
Programs are not user-friendly for producers	78	22.7%
Lack of effective technical assistance for your land/operation	50	14.5%
Operation does not meet program requirements	33	9.6%
Negative past experiences of a friend/family/peer with cost-share programs	22	6.4%

Note: Panel A 610 respondents; Panel B 617 respondents; Panel C 161 respondents; Panel D 344 respondents.

Table 5. Regression results.

Variable	(1)	(2)	(3)	(4)
Woody cover	0.006***	0.013***		
	(0.001)	(0.002)		
Square of woody cover		-2.1e-4***		
		(6.5e-5)		
Woody cover first spline			0.030***	0.005
			(0.006)	(0.018)
Woody cover second spline			-0.061***	1.064
			(0.015)	(0.692)
Woody cover third spline				-0.666
				(0.996)
Percent of land that is natural grass	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Percent of land that is tame grass	0.001*	0.001*	0.001*	0.001
	(0.000)	(0.000)	(0.000)	(0.000)
Water deficit	-0.001	-0.001	-0.001	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Degree days >34C	-0.007*	-0.007*	-0.007*	-0.005
	(0.003)	(0.003)	(0.003)	(0.003)
Degree days 10 - 34C	0.084**	0.087**	0.084**	0.112***
	(0.027)	(0.027)	(0.027)	(0.016)
Slope	-0.009**	-0.009**	-0.009**	-0.011***
	(0.003)	(0.003)	(0.003)	(0.003)
Sand content of soil	0.010***	0.009***	0.009***	0.007***
	(0.001)	(0.002)	(0.001)	(0.001)
Silt content of soil	0.012***	0.011***	0.011***	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
Soil organic carbon in soil	0.015**	0.014**	0.013**	0.016***
	(0.005)	(0.004)	(0.004)	(0.005)
Number of parcels in transaction	-0.019**	-0.019**	-0.020**	-0.022**
	(0.007)	(0.007)	(0.007)	(0.007)

Table 5. Continued.

Marginal Effects:				
Tree cover	8.67***	15.90***	26.69***	18.46***
	(1.44)	(2.62)	(4.32)	(6.76)
Observations	12,255	12,255	12,222	12,346

Note: Column 1 specifies woody cover linearly. Column 2 specifies woody cover as a quadratic. Columns 3 and 4 specify a restricted cubic spline on woody cover with 3 and 4 knots, respectively. Also controls for township and year effects. Standard errors clustered at year.

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

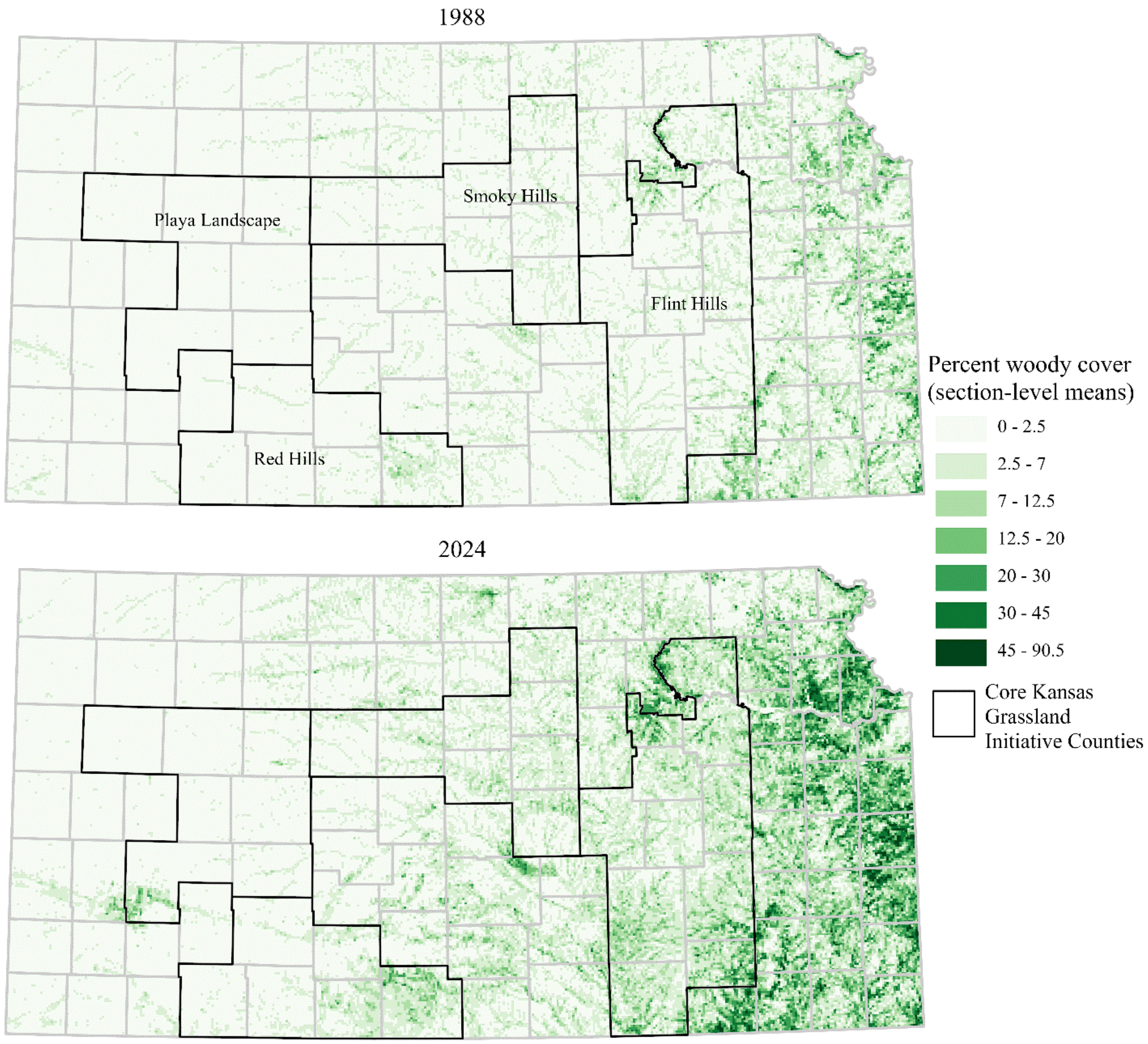

Figure 1. Woody cover in 1988 and 2024 for the four KGPGI priority areas. Woody cover from RAP are aggregated from 30-meter resolution up to PLSS sections. Woody cover is measured as the percent of land covered by woody species.

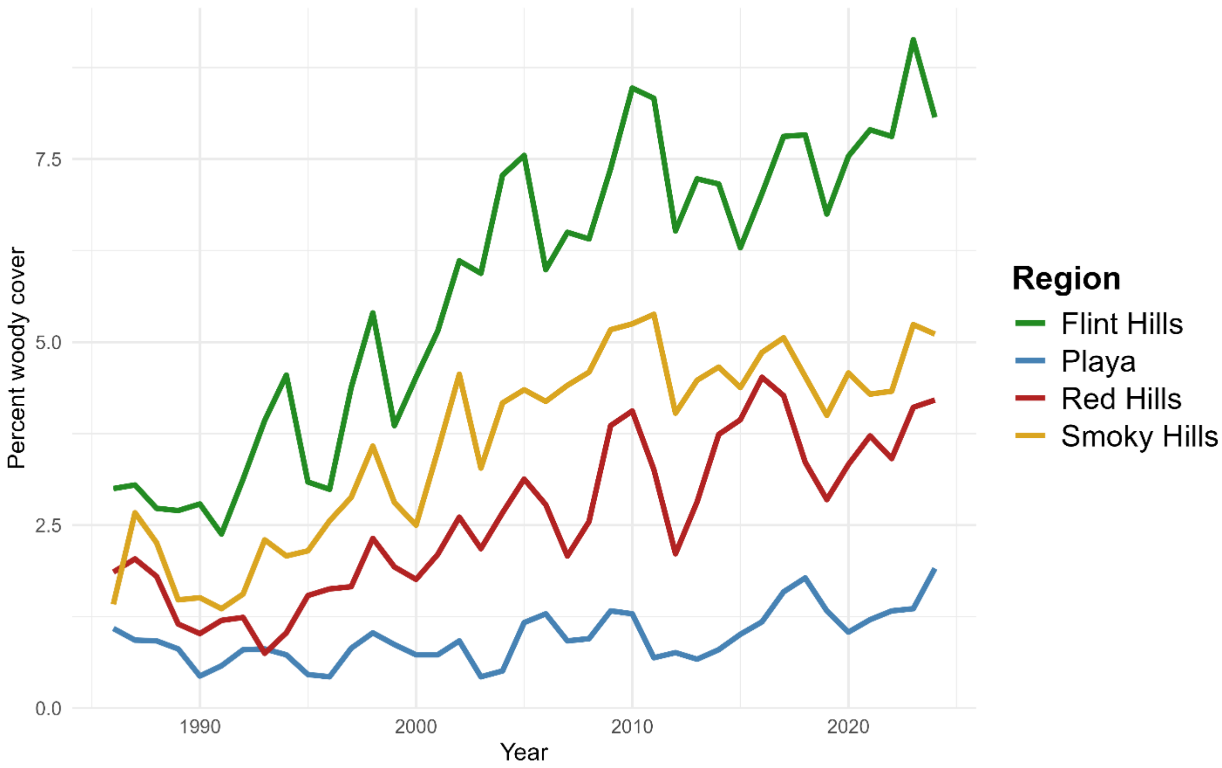

Figure 2. Change in woody cover over time for the four KGPGI priority areas. Woody cover data from RAP (30-meter resolution) are averaged across regions by year. Woody cover is measured as the percent of land covered by woody species.

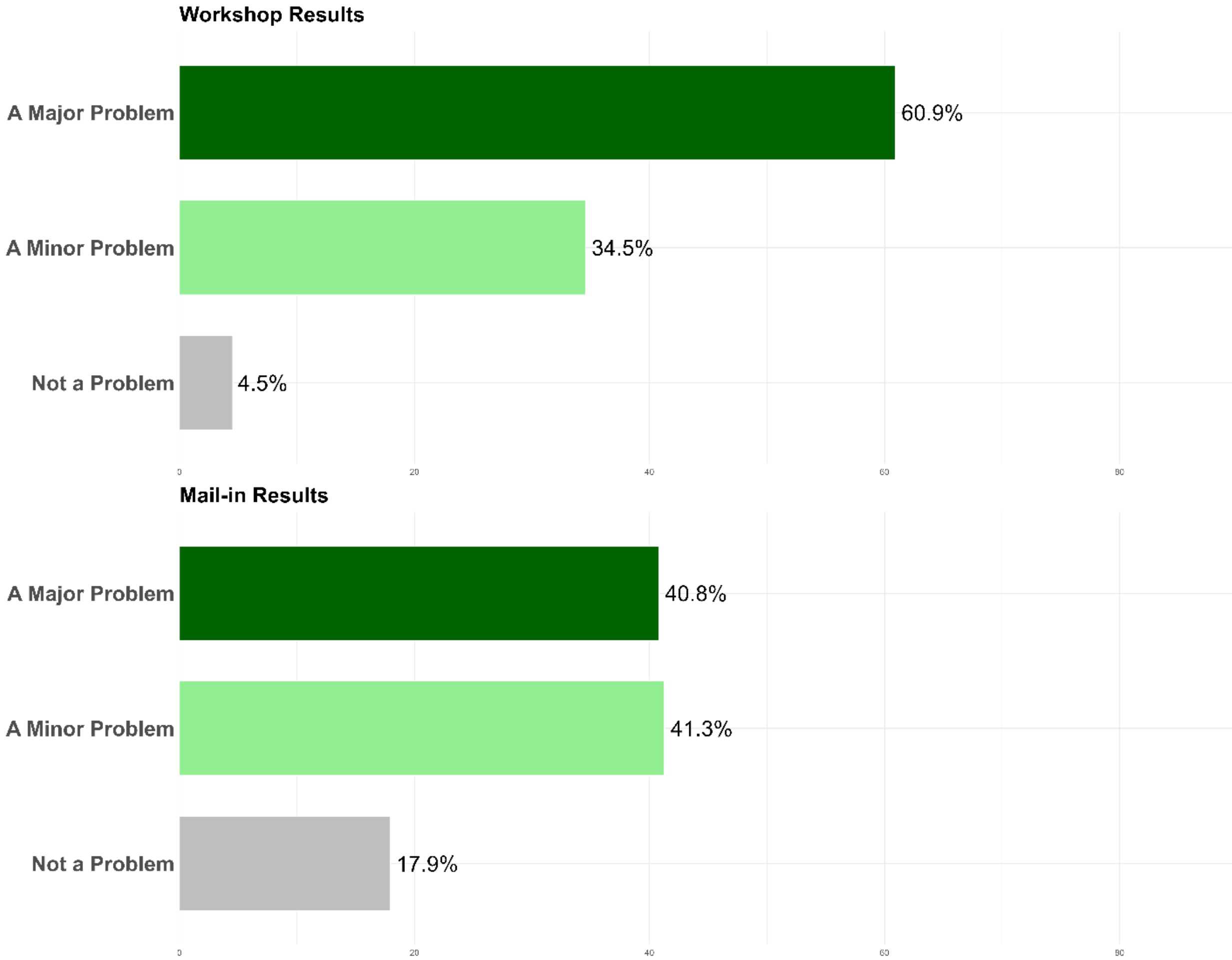

Figure 3. Survey response for perceived severity of woody encroachment on pasturelands obtained from workshop participants (top) and landowners (bottom). Note: 110 respondents from the workshop survey and 622 respondents from the mail survey.

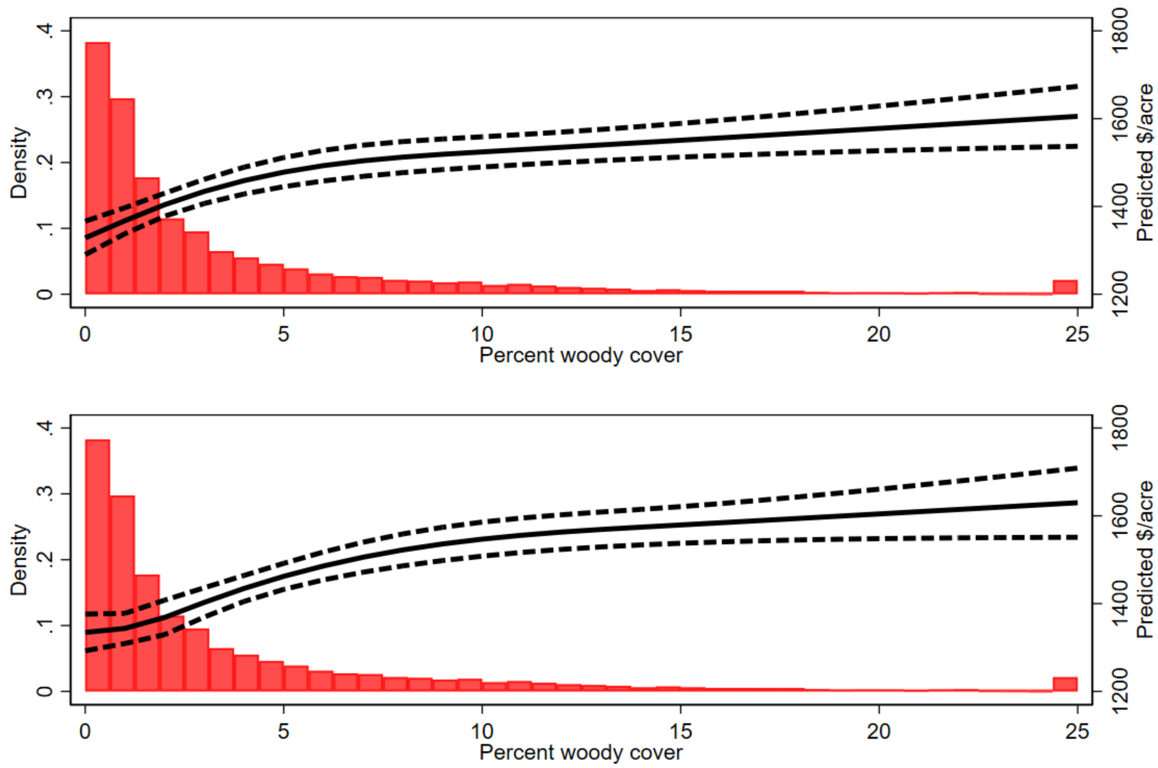

Figure 4. Predicted land values for different levels of woody cover plotted against a histogram of woody cover for land transactions. Restricted cubic spline with three knots at the 10th, 50th, and 90th percentiles of woody cover (top) and four knots at the 5th, 35th, 65th, and 95th percentiles of woody cover (bottom). Dotted line represents 95% confidence interval of prediction. Note that woody cover is censored at 25% in the histogram.

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