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# A Tale of Two Borders: Use-Value Assessment, Land Development, and Irrigation Investment

Daniel P. Bigelow      Todd Kuethe

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## **Abstract**

Since 1960, all 50 states in the US have adopted some form of preferential tax treatment for farmland. These provisions often take the form of use-value assessment, where farmland is taxed on the basis of its value in agricultural production, as opposed to its full market value. While the main goal of use-value assessment is to slow the conversion of farmland to non-agricultural uses, other channels of influence are also possible, such as those stemming from reinvestment of foregone tax expenses. Despite its widespread nature, there is little empirical evidence pertaining to the influence of use-value assessment on land-use or investment decisions. Using a postmatching difference-in-differences framework, we exploit the temporal and spatial discontinuities surrounding the adoption of use-value assessment in Kansas in 1989 to measure how use-value assessment affected plot-level land development and irrigation investment decisions. The results of our analysis indicate that, as intended, the use-value assessment policy curtailed development in the Kansas City metropolitan area. Evidence regarding the potential investment-spurring effects of use-value assessment is more mixed, suggesting that farmers may have increased irrigation in some areas because of use-value assessment-induced tax savings.

**JEL Codes:** Q15, R14, Q24

**Keywords:** property tax, irrigation, urban development, land-use policy and regulation

**Running head:** Use-value assessment

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All 50 states in the US provide some form of preferential tax treatment of agricultural land (Anderson and England, 2014).<sup>1</sup> Between 1960 and 1995, each state adopted a preferential taxation policy (Anderson and England, 2014). Preferential farmland tax treatment lowers the tax burden of farmland owners in an effort to reduce the conversion of agricultural land to alternative, generally developed, uses with higher private economic returns. In this respect, preferential taxation is borne of the same motivations as other policy tools designed to mitigate the negative side effects of excessive development (or “urban sprawl”), such as greenbelts, urban growth boundaries, and development impact fees (Nechyba and Walsh, 2004; Quigley and Rosenthal, 2005).

Preferential farmland tax programs take a variety of forms, but the most common type of policy is use-value assessment (UVA).<sup>2</sup> Under a pure UVA program farmland is taxed according to its value in perpetual agricultural use, as opposed to its full market value. This can have a significant effect on the values used in tax assessments, since the true market value of a farmland parcel may include capitalized future development returns that have yet to be realized by the landowner (Plantinga, Lubowski, and Stavins, 2002). By removing capitalized future non-agricultural use components from the land values used in tax assessments, landowners will, in theory, face less financial pressure to convert their land. In more remote rural areas where land is less susceptible to development pressure, UVA will have minimal effect on the likelihood of a farmland parcel being developed. In some states, however, UVA programs are explicitly designed to reduce assessed values beyond the amount solely attributable to capitalized future non-agricultural returns (Anderson and England, 2014), and may also decrease the volatility of property tax expenses for farmland owners, which some have suggested may lead to increases in farm investment (Conklin and Leshner, 1977).

This paper examines the degree to which UVA affects land development and farm investment. Using plot-level panel data on land use, we exploit variation in the timing of UVA implementation across states to study the effects of UVA adoption in Kansas in 1989. Kansas was a relatively late adopter of UVA and by 1989 all surrounding states had had a

preferential farmland tax policy in place for at least 14 years (Anderson, Giertz, and Shimul, 2015). Importantly, our data on development and irrigation decisions spans 1982-2012, covering the period before and after Kansas adopted UVA. In addition, we show that the UVA program adopted in Kansas reduced tax expenses in both the rural and more urbanized parts of the state, suggesting the policy may have had an effect on the investment behavior of landowners whose land did not have development potential. To identify the effects of UVA, we rely on variation in micro-level decision outcomes across state borders before and after Kansas's policy was implemented. We focus on how the policy affected two separate decisions of farmland owners. First, we analyze how UVA adoption impacts farmland development by focusing on the Kansas City metropolitan area, located along Kansas's eastern border. Second, we investigate how UVA adoption affects irrigation decisions at the extensive margin, specifically through groundwater irrigation along Kansas's western border overlying the Ogallala (or High Plains) Aquifer.

The existing literature provides little in terms of rigorous empirical evaluation of the effects of UVA and related policies. A significant share of prior research was conducted in the 1970s, when a large number of US states adopted preferential farmland tax policies in response to rising farmland prices (Blase and Staub, 1971; Schwartz, Hansen, and Foin, 1975, 1976; Conklin and Leshner, 1977; Coughlin, Berry, and Plaut, 1978). In a study explicitly designed to investigate the degree to which preferential tax treatment achieves its intended effect of reducing farmland conversion, Morris (1998) examines county-level trends in farmland retention before and after policy adoption and finds that reduced tax burdens for farmland owners are associated with a dampening of farmland loss. Polyakov and Zhang (2008) also show that differential property taxation slows the pace of development, and further demonstrate that land-use decisions are relatively inelastic with respect to incremental changes in property tax rates. Butsic, Lewis, and Ludwig (2011) show that rural property tax credits administered through a "circuit breaker" mechanism have a relatively weak influence on reducing development. In related research, preferential farmland taxation has been shown to reduce overall tax revenues surrounding metropolitan areas (Anderson and

Griffing, 2000) and shift the property tax burden to the owners of other types of property (Dunford and Marousek, 1981; Chicoine and Hendricks, 1985). A recent study by Dinterman and Katchova (2019) suggests that the financial impacts of changes in use-value calculations are shared by both farmland tenants and landlords. The impact of UVA of farm investment and production decisions is relatively unexplored, but was first suggested by Conklin and Leshner (1977), who theorized that preferential taxation policies have the potential to spur farm investment (or, equivalently, slow disinvestment) in urbanizing areas by reducing uncertainty over tax expenses. To our knowledge, there are no recent studies of how preferential tax policy affects irrigation or other investment decisions of farmland owners.

Our study also contributes to the broader literature on the effects of land-use policy on land-use decision-making, which includes a number of recent studies of the effects of various growth controls on development outcomes (such as Geshkov and DeSalvo, 2012; Dempsey and Plantinga, 2013; Wrenn and Irwin, 2015; Towe, Klaiber, and Wrenn, 2017; Dempsey et al., 2017; Zhang, Wrenn, and Irwin, 2017). This growing body of literature is the direct result of increased data availability and the rise of quasi-experimental methods in applied economic research. A quasi-experimental research design is crucial to the evaluation of land-use regulations, given that the placement and implementation of such policies are generally endogenously related to land market outcomes (see, e.g., Butsic, Lewis, and Ludwig, 2011). As a result, credible estimates of the effects of land-use regulations must exploit some plausibly-exogenous source of identifying variation, typically over time, to accurately capture the impact of policies on the rate, amount, or location of development. We are unaware of any existing empirical studies that focus on how farmland property tax relief might affect irrigation decisions, though Bigelow et al. (2017) show that the relative stringency of growth containment policies can influence the amount of irrigated land that remains in a city's environs.

This study makes several contributions to the literature on preferential farmland taxation. First, by using a panel of plot-level outcomes, our results provide micro-scale empirical evidence of UVA reducing land development, which, to our knowledge, has yet to be doc-

umented in existing studies. We find that development becomes significantly less likely, by roughly 1.8-3.4%, in Kansas due to the adoption of UVA. Moreover, we find that the bulk of the development effects manifest 13 years after the policy was adopted, with the effect tapering off thereafter, which suggests there are large option values associated with changes in expectations regarding development potential. These results also accord with the conventional wisdom regarding the temporary nature of how UVA disincentivizes farmland conversion (Anderson and England, 2014). Second, our results provide suggestive evidence that UVA adoption may have spurred an expansion of irrigated land in western Kansas. The results vary from state to state, with immediate increases ranging from 3.1-7.5% for land in Kansas counties bordering Colorado, but generally negative or null effects found for lands located along other border segments (Nebraska and Oklahoma). If UVA affected irrigation outcomes, the policy potentially exacerbated the open-access groundwater extraction problem in the Ogallala Aquifer, an unintended environmental consequence similar to results found in other public policy contexts (e.g., Stavins and Jaffe, 1990). However, our results also indicate that the changes along the Colorado border may have been partly driven by differences in farmland characteristics which made irrigation more likely on the Kansas side of the border.

### **Preferential Farmland Assessment in Kansas and Surrounding States**

Kansas, the focal point of our study, adopted its UVA policy in 1989, making it one of the last states to implement a preferential taxation program.<sup>3</sup> Although Kansas's policy was formally adopted in 1989, the legislation that eventually led to the policy was passed in 1985 (Kansas Department of Revenue, 2018). Prior to 1989, agricultural land in Kansas was assessed on the basis of 30% of fair market value.<sup>4</sup> Since adopting UVA, assessed values used for taxation purposes have been "based on the productive potential directly attributable to the natural capabilities of the land, not fair market value" (Anderson and England, 2014, p. 44). Variation in assessed farmland values, which are a function of the imputed eight-year rolling average of a hypothetical landlord's share of net farm income, stems from three main sources: (1) land use (i.e., cropland vs. grassland/pasture), (2) soil quality, and (3) county-

level variation in property tax rates. Under Kansas's UVA program, the assessment ratio, or the fraction of the assessed value actually used to compute tax expenses, remained at 30%.<sup>5</sup>

The four states surrounding Kansas all adopted some form of preferential farmland tax assessment well before Kansas: Colorado (1970), Nebraska (1972), Oklahoma (1974), and Missouri (1975). As described in more detail below, differences in UVA adoption timing between Kansas and its neighbors are critical to our identification strategy. However, agricultural property taxation is not static, and the methods adopted in individual states have shifted to varying degrees over time.

To isolate the potential effects of UVA on land development, we focus on the border Kansas shares with Missouri. The Kansas-Missouri border is straddled by the Kansas City metropolitan area, a large urban area that provides an ideal setting to assess the influence of the UVA policy on land development (figure 1). Missouri adopted its use-value assessment legislation in 1975 (Lapping, Bevins, and Herbers, 1977), but the process by which use values were to be determined was not formalized until 1985. Starting in 1985, Missouri farmland was formally assessed using a net income measure, which was subsequently switched to a measure based on cash rents, before reverting back to a net income measure in 2007 (Food and Agricultural Policy Research Institute, 2007).<sup>6</sup>

To study the impacts of UVA on irrigation decisions, we study (bi-directional) dryland-irrigated farmland conversions along the border Kansas shares with Colorado, Nebraska, and Oklahoma. The region is home to the Ogallala Aquifer, a major source of irrigation water supply, which spans a portion of all three border segments (figure 1). Irrigation in the region, primarily from groundwater, became widespread during the post-World War II era as farmers adopted new pumping and irrigation technologies that increased access to the aquifer and allowed corn to be grown in the area (Hornbeck and Keskin, 2014).<sup>7</sup>

Colorado, which shares the bulk of Kansas's border overlying the Ogallala Aquifer, adopted its UVA program in 1970. In Colorado, use-value estimates are derived from a net income approach, where assessed values vary based on a moving ten-year average of crop yields, the share of crops typically received by landlords, and typical landlord expenses (Col-

orado Assessors Association, 2019). Net income is converted to use value using a statutory capitalization rate of 13%, and property taxes are then computed using an assessment ratio of 29%.<sup>8</sup> Nebraska passed legislation to allow for use-value assessment in 1972, but the program has evolved over time due to legal conflicts.<sup>9</sup> Since 1992, farmland property has been assessed under a classified-use system. Under this system, taxes in Nebraska were initially based on 80% of the full market value of the land, with the fraction reduced to 75% in 2007. As a result, Nebraska has by far the least generous farmland property tax system (from a landowner's standpoint) in our study area (Midwestern Office of the Council of State Governments, 2012). Lastly, Oklahoma began implementing use-value assessment in 1974 using an income capitalization approach based on prevailing cash rental rates (Hapgood, 2010; Anderson, Giertz, and Shimul, 2015), adjusted for soil quality. Starting in 1981, Oklahoma switched from a rent-based method to one based on a classification scheme of "productivity points" which are a function land use, soil type, and the corresponding soil productivity index. With the exception of a few minor adjustments to update the soils data used in determining assessed values, the Oklahoma UVA methodology has remained unchanged since 1981.

Of three states neighboring the western portion of Kansas, Colorado and Kansas have the most similar UVA programs, especially given the comparable assessment ratios used in both states. Oklahoma's program is also comparable in spirit, though based on its own idiosyncratic productivity index which implicitly places a heavy discount on the true use value of agricultural land. Further, the tax policies in both Colorado and Oklahoma have changed little since their initial implementation in the 1970s. Nebraska, by contrast, features a program that currently bears little resemblance to those in the other three states and, furthermore, one that has changed significantly over the study period.

### **Supporting Evidence**

Of primary importance to our identification strategy is the late adoption of preferential farmland taxation in Kansas relative to its neighboring states. Although the intent of Kansas's use-value assessment policy was to reduce property taxes on farmland with development

potential, this may not necessarily hold for land located in more remote areas, where use values could conceivably be larger than market values. Moreover, the farmland assessment ratio of 30%, which remained constant before and after the UVA policy was implemented, is substantially higher than those presently used for other land classes in Kansas, such as the 11.5% rate imposed on residential land (Hildreth, 2018), which makes it unclear if the policy change led to a meaningful reduction in property taxes for any farmland owners. What is key, then, is whether or not the computed use values are lower than the corresponding market values. To show that the UVA policy did indeed result in a windfall gain for farmland owners throughout the state, we estimate a set of county-level regression models using reported farmland property tax expenses for 1987 and 1992.<sup>10</sup> We focus on 1987 and 1992 to match the quinquennial frequency of our main data source described below. The estimation dataset includes all counties in the five states in the study area (Kansas, Missouri, Colorado, Oklahoma, and Nebraska) that reported farmland tax expenses in both years. The tax expense measures are adjusted for inflation using the GDP implicit price deflator available from the Bureau of Economic Analysis. While the UVA legislation in Kansas was passed in 1985, the actual policy did not go into effect until 1989, and thus the 1987 tax expenses in Kansas were still administered under the previous taxation framework based on market value. We do note, however, that we can not rule out that the 1987 tax expenses may be influenced by actions taken in anticipation of the eventual implementation of the policy. If anything, however, this would bias these first-stage estimates upward, making the estimates conservative.

To generate the effects of interest, we regress logged farmland tax expenses on a set of county fixed effects and allow for differential 1992 (post-UVA) effects for Kansas. Standard errors are clustered by USDA agricultural district, of which there are 41 in the entire five-state region. The results, with marginal effects in brackets, are shown in table 2. Using all counties in the study area, the post-UVA regression coefficient for Kansas amounts to a marginal effect of -12.49%, indicating a clear reduction in tax expenses for the population of Kansan landowners. This suggests that use values were 12.49% lower than the previous

market values upon which tax assessments were made. If the UVA policy induced any short-term value-increasing investment behavior, this should be interpreted as a lower bound on true magnitude of the difference between use and market value. To show that the policy affected both rural and periurban tax expenses, we split the sample up based on the 75th percentile of the population density distribution for 1987.<sup>11</sup> Strong negative coefficients of -13.52% and -8.94% emerge for both the rural and more urban segments of the dataset, respectively. Similar results are obtained if we use alternative property tax variables, such as the effective farmland property tax rate (tax expense divided by land value), property taxes per farm, and property taxes per farmland acre. The only coefficient estimate with a  $p$ -value greater than 0.1 is that for the effective property tax rate in urban counties. The lack of precision is likely attributable to the relatively small sample of urban counties. We show in Appendix A that these regression results are insensitive to the use of farmland acreage weights.

In the appendix, we also present historical state-level trends in the same farm property tax variables from U.S. Department of Agriculture (2014). The state-level data predate the availability of the Census data, and thus provide a longer, though coarser, depiction of how the UVA policy affected Kansas relative to its neighbors. For all of the same variables, whether taking the change over 1982-1992 or 1987-1992, Kansas has either the biggest decline or smallest gain. The preceding analysis provides firm evidence that Kansas's adoption of the UVA policy in 1989 led to meaningfully different farmland property taxation rates in both urban and rural areas, which we use as motivation for the subsequent analysis.

## **Model**

In this section we motivate our empirical application by providing a conceptual overview of the relationships use-value assessment shares with land development and irrigation decisions. We then present our empirical model and discuss key aspects of our identification strategy.

### *Conceptual Model*

The relationship between UVA and land development decisions was formalized by Anderson (1993), which we briefly review here to illustrate the mechanisms at work in our empirical

application. Following prior work on urban economic theory, Anderson's (1993) model posits that the per-acre value of a parcel of land is determined by the sum of two discounted streams of future returns: (1) the net income stream generated by farming,  $f(t)$ , which is pertinent until period  $D$ , when (irreversible) development occurs, and (2) the subsequent discounted net income stream accruing from development. The landowner, therefore, selects the optimal time of development,  $D$ , to maximize the parcel's value,  $V(t, D)$ .

When land is taxed at its market value, the tax expenses owed by farmland owners may be written as:

$$(1) \quad \tau\delta^F V^F(t, D) = \tau\delta^F \left\{ \int_t^D f(u)e^{-(r+\tau)(u-t)} du + e^{-(r+\tau)(D-t)} \int_D^\infty h(u, D)e^{-(r+\tau_a)(u-D)} du \right\}$$

where  $r$  is a constant discount rate,  $\tau$  is the property tax rate (or millage rate), and  $\delta^F$  is the assessment ratio (Anderson, 1993). The assessment ratio is bound between 0 and 1 and represents the fraction of the assessed value that is used in computing property taxes. This contrasts with the property tax expenses landowners face under use-value assessment:

$$(2) \quad \tau\delta^U V^U(t, D) = \tau\delta^U \left\{ \int_t^\infty f(u)e^{-(r+\tau)(u-t)} du \right\}.$$

Intuitively, the land development effect brought about by UVA centers on the presumption that  $\tau\delta^U V^U(t, D) \leq \tau\delta^F V^F(t, D)$ . If this holds, either through a lower assessed value ( $V^U(t, D)$ ) or assessment ratio ( $\delta^U$ ) under UVA, then UVA reduces property tax payments for farmland owners and disincentivizes development by increasing the opportunity cost of converting their land. In practice, one would expect  $V^F(t, D)$  to converge to  $V^U(t, D)$  the further one moves away from the rural-urban fringe. The large disparity between  $V^F(t, D)$  and  $V^U(t, D)$  has been demonstrated in numerous empirical applications (e.g., Zhang and Nickerson, 2015). As a result, UVA, in its purest form (i.e., where  $\delta^U = 1$ ), should have minimal effect on the rate of farmland development in rural areas.

As it relates to our study area, one important farm investment decision that could be affected by UVA is the use of irrigated, rather than dryland, production. Following Negri,

Gollehon, and Aillery (2005) and Chambers and Just (1989), the annual net return to agricultural production in (1) and (2),  $f(\cdot)$ , can be expressed as multi-output indirect profit function. Let  $\mathbf{Y}$  be a vector of agricultural commodity outputs and  $\mathbf{P}$  be a vector of exogenous output prices. Farms employ a vector of variable inputs  $\mathbf{X}$  (e.g., water, labor, fertilizer, energy, etc.) based on an associated vector of exogenous input prices  $\mathbf{W}$ . Farms operate a quantity of fixed, allocable land, represented by the scalar  $N$ , that is subject to tax rate  $\tau$  and assessment ratio  $\delta$ . The discrete choice of irrigation is represented by the scalar  $\mathcal{S}$ , which is associated with a lump-sum annualized capital cost of irrigation  $\omega$ . Indirect profits are also subject to exogenous physical characteristics  $\Theta$ , such as soil conditions and climate, which affect production.<sup>12</sup> The indirect profit function takes the form:

$$(3) \quad f^j(\mathbf{P}, \mathbf{W}, \omega, \delta^j, \tau, N, \Theta) = \max_{\mathbf{X}, \mathcal{S}} [\mathbf{P}'\mathbf{Y} - \mathbf{W}'\mathbf{X} - \omega\mathcal{S} - \tau\delta^j NV^j(D) \mid \mathbf{Y} \in Y(\mathbf{X}, \Theta, N, \mathcal{S})]$$

where  $Y(\mathbf{X}, \Theta, N, \mathcal{S})$  is the restricted production possibilities set and  $j = F, U$  indexes the method of property tax assessment.

Irrigation adoption is assumed to be discrete and dichotomous in equation (3), with  $\mathcal{S}_I$  and  $\mathcal{S}_D$  representing production technology for irrigation and dryland production, respectively. As formulated, our model is static and we implicitly assume that the necessary water conveyance structures and water rights are already in place and available to the farmer.<sup>13</sup> Separate indirect profit functions associated with irrigated and dryland production can be written as:

$$(4) \quad f_I^j(\mathbf{P}, \mathbf{W}, \omega, \delta^j, \tau, N, \Theta) = \max_{\mathbf{X}} [\mathbf{P}'\mathbf{Y} - \mathbf{W}'\mathbf{X} - \omega\mathcal{S}_I - \tau\delta^j NV^j(D) \mid \mathbf{Y} \in Y(\mathbf{X}, \Theta, N, \mathcal{S}_I)]$$

and

$$(4') \quad f_D^j(\mathbf{P}, \mathbf{W}, \delta, \tau, N, \Theta) = \max_{\mathbf{X}} [\mathbf{P}'\mathbf{Y} - \mathbf{W}'\mathbf{X} - \tau\delta^j NV^j(D) \mid \mathbf{Y} \in Y(\mathbf{X}, \Theta, N, \mathcal{S}_D)].$$

The profit-maximizing farm operator adopts irrigation when the net returns from doing

so (4) exceed the returns from dryland farming (4'). Adoption of use-value assessment will create an incentive to invest in irrigation if  $f_I^U(\mathbf{P}, \mathbf{W}, \omega, \delta^U, \tau, N, \Theta) > f_D^F(\mathbf{P}, \mathbf{W}, \delta^F, \tau, N, \Theta)$ . In theory, use value should deviate minimally from market values in rural areas. As shown in the previous section, however, even with a constant assessment ratio, rural landowners in Kansas experienced a 13.5% reduction in property tax expenses after UVA was passed, suggesting that use values are lower than corresponding market values. Additionally, the formulaic determination of assessed values under UVA may provide more stable and predictable farmland tax expenses compared to those based on more volatile market values, which Chicoine and Hendricks (1985) notes may lead to additional investment.

### *Empirical Model*

We estimate the impact of UVA on two outcomes: (i) conversion of farmland to developed use and (ii) conversion between dryland and irrigated agricultural production. Our empirical approach combines generalized post-matching difference-in-differences (DD) estimation with the contiguous border county-pair framework of Dube, Lester, and Reich (2010).

For each plot observation,  $i_k$ , in the development model, we construct a binary variable  $D_{i_k t}$  that takes a value of 1 if the parcel is in developed use at time  $t$  and 0 otherwise. In our notation,  $i$  indexes a physical plot of land we observe over time and  $k$  indexes the instances of the plot's time series appearing in the sample, which is explained further below. We treat development decisions as irreversible and our model is therefore estimated using parcels where  $D_{i_k 1} = 0$ . Parcels drop out of the estimation sample once they are converted, making the panel unbalanced. The probability that an undeveloped parcel is developed between the baseline period and time  $t$  is estimated using:

$$(5) \quad \text{Prob}(D_{i_k t} = 1) = \beta_{1t} U_t^B K S_i + \alpha_{1t} U_t^A K S_i + \mathbf{X}_i^{D'} \boldsymbol{\rho}_1 + \phi_{1t} B P_{i_k}^D + \tau_{1t} + \varepsilon_{i_k t}.$$

The indicator variables  $U_t^B$  and  $U_t^A$  represent the respective periods before and after UVA is implemented. Differential pre-treatment time effects associated with being located in the UVA treatment area ( $K S_i$ ), Kansas, are thus measured by  $\beta_{1t}$ . Common time fixed effects are captured by  $\tau_{1t}$ . Of primary interest are the differential effects for Kansas in periods

after UVA was implemented, which are estimated by  $\alpha_{1t}$ . The model also accounts for observable factors  $\mathbf{X}_i^D$  that may influence land development. The  $D$  superscript is included on the vector of observable covariates to highlight that the explanatory factors included in the development and irrigation models may differ.

Similar to Dube, Lester, and Reich (2010), to minimize potential bias stemming from unobserved spatial heterogeneity, we include in (5) a complete set of cross-border contiguous county pair indicator variables ( $BP_{ik}^D$ ). We construct this vector to cover all cross-border contiguous county pairs in the study region. Since counties may be contiguous to more than one cross-border county, each plot  $i$  entering (5) is indexed by  $k$  to account for the fact that a plot may enter the dataset multiple times. For an individual parcel observation,  $k = 1, \dots, K_i$  indexes the number of times a plot's county is contiguous to (or shares a border with) another county on the opposite side of the Kansas border. We also allow the border-pair effects,  $\phi_{1t}$ , to vary over time to account for unobserved temporal variation common to each border pair.

We construct a similar model to estimate the impact of UVA on irrigation adoption on cropland along Kansas's western border. For each parcel  $i$ , a binary indicator variable  $I_{i_k t}$  takes the value of 0 if the parcel is in dryland production or the value of 1 if the parcel is irrigated at time  $t$ . The probability that a parcel is irrigated at time  $t$  can be expressed:

$$(6) \quad \text{Prob}(I_{i_k t} = 1) = \beta_{2t} U_t^B K S_i + \alpha_{2t} U_t^A K S_i + \mathbf{X}_i^I \boldsymbol{\rho}_1 + \phi_{2t} B P_{ik}^I + \tau_{2t} + \varepsilon_{i_k t}.$$

All terms in (6) are defined analogously to those in (5), although the study area (and consequently the relevant border pairs in  $B P_{ik}^I$ ) and specific control variables included in  $\mathbf{X}_i^I$  differ. It is also important to note that we treat dryland-irrigated cropland conversions as reversible, meaning that farmers may switch from dryland to irrigated or irrigated to dryland production. In contrast to 5, estimation of 6 is thus conducted with a balanced panel and the UVA effects for the irrigated conversion model  $\beta_{2t}$  captures the net effect of UVA adoption on irrigated conversion decisions. It is plausible that both types of transition would be influenced by the UVA policy. Irrigation investment, entailing a switch from dryland to irrigated production, could be brought about by UVA through reduced expenditures on

taxes. Likewise, a switch to UVA could also stimulate a greater resilience to increased energy costs for irrigation amid declining aquifer levels, a major issue in the Ogallala region (Scanlon et al., 2012).

### *Identification Strategy*

Our identification strategy for estimating the effects of Kansas’s UVA policy consists of five components. First, we exploit temporal discontinuities across states in the timing of UVA adoption. Specifically, Kansas did not adopt UVA until 1989, well after neighboring states had adopted similar policies. The change in Kansas’s UVA status serves as our source of temporal variation to study the effects of farmland tax policy changes on land use and irrigation investment decisions. Prior to 1989, the opportunity cost of developing farmland would have been relatively lower in Kansas, since the net returns to farming would have been lower due to the higher rate of farmland taxation. Likewise, we investigate whether the tax savings from the switch to UVA resulted in more irrigated land in Kansas after 1989. To utilize these differences in UVA adoption timing, we rely on a panel dataset of plot-level observations of both land-use classification and irrigation status spanning a timeframe covering years before and after Kansas implemented UVA (1982–2012).<sup>14</sup>

Second, to mitigate the potential for confounding factors to bias our estimates, we adopt the contiguous-border county-pair strategy developed by Dube, Lester, and Reich (2010). Specifically, we stack our data and include in the specifications a complete vector of border-pair dummy variables for the counties located along the Kansas border. Stacking the data is required because of the many-to-many relationship that characterizes contiguous cross-border county pairs. Without stacking, equations (5) and (6) are not estimable due to the fact that each plot’s county may share the border with more than one county, resulting in perfect collinearity between the dummy variable regressors. In stacking the data, we incorporate the observations for plot  $i$  for each of the  $K_i$  border pairs to which its county belongs.<sup>15</sup> In addition, we further control for time fixed effects common to each individual border pair, which, for example, accounts for the possibility that the northern and southern portions of the Kansas City metro area developed at different rates over time. The rationale

behind including the contiguous cross-border county-pair effects relies on the idea that plots in adjacent counties will be more similar to one another in terms of local economic structure, agricultural production, and other factors not captured explicitly in the model specification, thus serving as a more valid control group to study the effects of changes in farmland tax policy. Of course, the validity of the cross-border control group hinges on there being no other contemporaneous changes to farmland tax policy or other state-specific factors that affect irrigation and land development over the study timeframe.

Third, to further narrow the source of variation used to generate our estimates, the samples are restricted to plots contained within a pre-specified bandwidth of the Kansas state border. We generate estimates for bandwidths of 5–25 miles in five-mile increments. The restriction is meant to further mitigate potential bias stemming from unobserved spatial heterogeneity. This is particularly important given the size of some counties in the study area. We also report estimates derived from a “no-bandwidth” sample containing all plots in the relevant counties adjacent to the border.

Fourth, our preferred estimates are derived from a sample matched on propensity scores measuring the likelihood of a plot being located in Kansas based on its observable characteristics.<sup>16</sup> As in Chen, Lewis, and Weber (2016), we use nearest-neighbor 1:1 propensity score matching without replacement and a caliper equal to one-quarter of the standard deviation of the estimated propensity scores.<sup>17</sup> Note that the propensity score model is estimated using the unstacked version of the estimation dataset. Otherwise, the matching coefficients would be biased towards observations located in counties with a greater number of contiguous cross-border neighbors. The matching attributes are measured at the plot level using data from the USDA’s National Resources Inventory (NRI) and are described in greater detail below. We estimate a single propensity score model for each study area (Kansas City and western Kansas) and bandwidth (5–25 miles or no bandwidth). After estimating the propensity scores, we apply the stacking procedure described above and only allow matches to occur within cross-border contiguous county pairs. However, since a plot may not have a match within all of its associated border pairs, the number of times each plot appears in

the matched sample will be less than or equal to the number of times the plot appears in the unmatched sample. Matching is intended to produce a more comparable set of treatment and control plots, which is especially important in our case given that we do not have observation-level fixed effects in the model specifications.

Finally, we include a vector of observable covariates,  $\mathbf{X}_i^D$  or  $\mathbf{X}_i^I$ , to account for observable factors that may influence the outcomes of interest, which increases the precision of our estimates and further narrows the range of possible sources of unobserved confounding variation. As described below, the controls include plot characteristics from the NRI and various baseline county attributes.

In sum, the UVA estimates can be thought of as average treatment effects on the treated (ATTs) identified through cross-border variation in plot-level development and irrigation investment outcomes using a matched sample within a pre-specified bandwidth of the Kansas border, conditional on common border pair time effects and observable plot characteristics and county attributes. By stacking contiguous cross-border county pairs, the UVA estimates are computed by averaging over all estimated local ATTs for each border pair. In this sense, our adopted approach incorporates elements of DD, matching, and regression discontinuity design estimation strategies. The models are estimated in linear probability form to avoid the convergence issues associated with the incidental parameters problem in non-linear binary-choice models.

A somewhat unique feature of our study is that we are studying the effect of UVA in Kansas in relation to neighboring states, all of which had already adopted some form of preferential tax assessment prior to the start of our study time period. This contrasts with the typical two-by-two DD case comparing two groups without a treatment, which is subsequently assigned to one of the two, with the other serving as a nonexperimental control group. Our application can be thought of as a special two-group case of the more generalized situation in which all groups eventually receive a treatment. As Goodman-Bacon (2018) shows, if all observational units receive a treatment at some point, the eventual source of variation used to identify the treatment effect is the same as that used in the present study.

This comes at the point when all but one unit has received the treatment, in which case the remaining variation stems from control groups comprised of units that have already been treated. An obvious implication of relying on this type of variation, however, is that we are unable to use parallel trends as a means to determine the comparability of the treatment and control groups prior to Kansas adopting UVA. The use of a matched sample should, in part, alleviate concerns over the comparability of the treatment and control groups.

## **Data and Summary Statistics**

In this section, we provide an overview of our data sources and present summary statistics for the samples involved in our econometric application.

### *Data Sources*

The USDA-Natural Resources Conservation Service’s (USDA-NRCS) NRI is the primary data source for our analysis. The NRI is a panel dataset of plot-level land-use observations covering 1982-2012 in five year increments. Derived from a combination of remote-sensing analysis and physical site inspection, the NRI data consists of over 300,000 land segments and 800,000 core sampling points covering the contiguous US (USDA-NRCS, 2012). Each NRI observation is associated with an expansion factor (or survey weight) which represents the acreage attributable to that plot.<sup>18</sup> From the NRI data, we obtain information on land use (cultivated/uncultivated cropland, pasture, urban) and irrigation status.<sup>19</sup> The NRI data also provide a number of plot-level attributes measuring land capability class, slope, erodibility, flood potential, soil hydricity, and prime farmland.<sup>20</sup> Prior to estimation, we adjust the expansion factors to reflect the number of times each plot is stacked in the estimation data set. For instance, if plot  $i$  is located in a county with  $K_i$  cross-border adjacent counties, the expansion factor,  $x_i$ , is rescaled to  $x_{(k)i} = x_i/K_i$  prior to estimation. The expansion factors are readjusted after matching to reflect the number of times each plot is stacked in the matched samples. Although the NRI plot locations are confidential, we obtained supplemental data on several important spatial characteristics for the plots in our sample, including distance to nearby urban areas and distance from each plot to the Kansas border, which is critical to our identification strategy. Given its granular scale and consistent

panel structure, a number of prior studies have used the NRI data to estimate econometric models of land-use change (e.g., Lubowski, Plantinga, and Stavins, 2006, 2008; Lewis et al., 2011; Lawler et al., 2014; Claassen, Langpap, and Wu, 2017).

In addition to the NRI data, we obtain information on several county attributes. For the land development model, we include measures of baseline population density, total population, median household income, and baseline farm real estate value (\$/acre). In the irrigation adoption model, in addition to the farm real estate value, we include baseline shares of irrigated farmland, farmland rented, and farmland under a corporate ownership structure. All of these county-level measures enter into our model specification using their baseline, initial-year (1982) values, making them time-invariant. We do this to avoid the bias that would result from confounding, for example, a change in population density with the change in land development due to UVA.

### *Summary Statistics*

Before presenting the estimation results, we present and discuss summary statistics for the development and irrigation adoption samples.

#### *Development model sample*

The baseline sample for the land development model consists of all plots in the Kansas City CSA that are not developed as of 1982 or in one of seven auxiliary land uses (other rural land, rural transportation, small water, census water, federal land, and land enrolled in the Conservation Reserve Program) in any year between 1982 and 2012. We also screen the sample for plots that are at one point labeled as being developed, but then revert to an undeveloped use, which reflect outliers that we presume are more likely reflective of measurement error than a true land-use change. Overall, 5.8% of the development sample is converted at some point over the 1982-2012 study period, with 5.3% and 6.3% of the Kansas and Missouri samples being converted, respectively. The development pattern follows the same general trajectory on both sides of the Kansas border, with conversions peaking in the 1992-1997 and declining thereafter (table 1).<sup>21</sup> The difference for 1982-87 is quite stark, however, as development increased rapidly in Missouri and quite modestly in Kansas,

which highlights the importance of controlling for these pre-UVA trends in the econometric specification.

We check for covariate balance between the Kansas and Missouri observations before and after matching using normalized mean differences (NMDs) of the plot characteristics.<sup>22</sup> In the context of matching applications, Imbens and Wooldridge (2009) note that normalized mean differences in excess of  $|0.25|$  can be problematic. Figure 2 displays the NMDs using a 10-mile bandwidth and the full Kansas City CSA border sample for the matched and unmatched samples.<sup>23</sup> In the majority of cases, matching reduces the observable differences between plots in Kansas and Missouri. One exception is for the distance to the second nearest urban area, which is associated with the only NMD above  $|0.25|$  in each matched sample. Other cases where the matched sample produces a larger NMD are few in number and amount to modest increases with NMDs remaining below  $|0.25|$ .

#### *Irrigation model sample*

The irrigation adoption model sample consists of all NRI plots that are either solely used for cropland or used for a mix of cropland and pasture/range for the entire 1982-2012 period. With the exception of the Kansas-Colorado border, observations are included if they are located in a county with at least 25% of its area overlying the Ogallala Aquifer. The Kansas-Colorado border area is excluded from this latter screen because the 25% cutoff excludes some larger counties that have sufficient aquifer coverage near the state border. Overall, 29% of the land in the western Kansas sample is irrigated at some point over the 1982-2012 study period. A total of 4.6% of land converts from dryland to irrigated use, 5.6% converts from irrigated to dryland use, and 2.4% switches back and forth between the two uses, with the remaining 87% undergoing no change in irrigated status.

Table 1 shows separate trends in irrigated acreage for each border segment using the total samples in each county.<sup>24</sup> Along the Colorado border, the trends differ early on in the sample (1982-1997) before trending in similar directions from 1997 to 2012, with both states seeing fairly substantial declines in irrigated acreage over the 1982-2012 period. For the Nebraska border segment, the trends diverge substantially for the entire study period, which ends with

Nebraska seeing a much larger gain in irrigated acreage compared to Kansas. The aggregate trends for the Oklahoma border are also opposite, such that the Kansas sample generally experiences gains in irrigated land when losses occur in Oklahoma, and vice versa, resulting in a decline in irrigated land in Oklahoma and a gain of equal magnitude in Kansas. Although we emphasize that these figures convey simple trends with no controls, they indicate that irrigated acreage has trended differently for the Kansas and neighboring-state plot samples, particularly for the Nebraska and Oklahoma border segments.<sup>25</sup> Similar to the development samples, matching tends to improve covariate balance for the irrigation samples, particularly in cases where unmatched NMDs are especially large (figure 3).<sup>26</sup>

## Results

The econometric results are discussed below. Standard errors in each model are clustered at the plot level to account for serial correlation in plot outcomes and the stacked nature of our data which causes many plots to appear multiple times in a given year. We present only the UVA effects in this section. Estimates for the other covariates in the models are provided in Appendices D and E.

### *Development Model*

The primary estimates of the UVA treatment effect on land development are presented in table 3. Results indicate that Kansas saw large declines in developed acreage between 1982 and 1987. The 1987 point estimate is largest for the 5-mile buffer, amounting to a 4.2% reduction in development, and more modest, ranging from -1.2% to -2%, in other years. Kansas passed its UVA legislation in 1985 but did not formally adopt a UVA policy until 1989, so it is conceivable that some landowners were reluctant to develop their land in light of the upcoming tax policy change. However, given the five-year gap between observations in our data, it is not possible with our data to say with any degree of certainty whether or not the 1987 effect can be attributed to the UVA policy. The point estimates are generally negative, but noisy, for 1992 and 1997, the first years of our data following implementation of UVA. From 2002 onward, we find consistently negative and significant effects across all samples. The estimates indicate that development decreased in Kansas by 1.8-3.4% by 2002,

1.1-2% by 2007, and 1-2.7% by 2012. These estimates are always largest for the narrowest bandwidth (5 miles), smallest for no-bandwidth sample, and largest in 2002. The lack of a strong, consistent effect of the UVA policy on development until 2002 is potentially explained by the irreversible nature of farmland conversion. Specifically, there are large option values associated with the decision to develop farmland (Plantinga, Lubowski, and Stavins, 2002), which may create a lag in how landowners update their expectations in response to the tax policy change.

Overall, the matched sample produces results that are consistent with the intended goal of the UVA policy, namely to provide Kansas farmers with tax relief that slows the conversion of farmland. Appendix D shows results that illustrate the substantial effect that matching can have on the UVA point estimates. With the exception of the 1987 effects, which remain negative, the development model based on the unmatched sample produces effects with opposite signs and/or significance levels in nearly all cases and broadly suggest that development in Kansas increased in the near-term, followed by no further changes throughout the study period aside from a small, marginally significant effect for 2012 with the 5-mile bandwidth. The substantive effects matching can have on the estimation of policy treatment effects has been documented in previous studies (Ferraro and Miranda, 2014, 2017).

Although matching increases the covariate balance between treatment and control groups, achieving perfect balance is not a practical goal for policy evaluations based on observational data. As a robustness check, we assess the extent to which the UVA effects may result from higher development likelihood for plots with certain characteristics after the UVA policy went into effect. For example, distance to urban areas may have become more important after the UVA policy went into effect given the change in incentives brought about by the program. To account for this possibility, we follow Dempsey and Plantinga (2013) and reestimate the matched version of equation 5 using a specification that includes interactions between the plot attributes and a post-UVA dummy variable, which takes a value of 1 for all years after 1989 (i.e., 1992 and beyond). Results from this specification are unchanged, and exhibit

slightly improved precision over those derived from the baseline specification (Appendix D). In Appendix D, we also show that the development results are insensitive to the use of a sample matched with replacement.

### *Irrigation Model*

Irrigation model estimates for each border segment are provided for the 10-mile, 20-mile, and no-bandwidth samples in table 4. Estimates from alternative bandwidths are shown in Appendix E. For Colorado, the UVA effect estimates indicate an increase in irrigation in Kansas between 1982 and 1987 ranging from 1.8-5.2 but the effects are insignificant in half of the samples. In 1992, the first year we observe after the UVA policy was in place, irrigation increased in Kansas by 3.1-7.5%, with larger effects deriving from the smaller bandwidths. Estimates for years after 1992 are always positive, but the precision is inconsistent across the different bandwidth samples. The 5- and 10-mile bandwidth samples produce no significant effects, while those for the 15- and 20-mile samples yield at least some precision in most years. The larger bandwidths generally do not produce significant effects. UVA effects from the unmatched samples are similar to the matched ones, but yield significant estimates for the smaller bandwidths in later years (Appendix E). Estimates from the specification with post-UVA attribute interactions are mostly positive but generally lack significance (Appendix E). This suggests that the effects on irrigation outcomes, particularly in later years, may derive from Kansas farmland being more amenable to irrigation. The 1992 effect for the 10-mile buffer, however, remains significant at the 5% level.

Results for the Nebraska border segment, generally speaking, are opposite those found along the Colorado border segment. With few exceptions, we find null effects for 1987 and 1992, as well as the 5- and 10-mile bandwidth samples. For bandwidths of at least 15 miles and for later years, however, we find significant negative effects ranging from 3.1-10.8%, which become larger over time but exhibit no clear pattern across the bandwidth sizes. A similar pattern of negative effects is found with the unmatched samples and after allowing for post-UVA attribute interactions (Appendix E). Effects for the Oklahoma sample are generally insignificant, with signs flipping both over time and between different bandwidths. Without

matching (Appendix E), several of the earlier negative become significant, while several additional positive effects emerge for later years. The post-uva interaction specification produces similarly inconsistent estimates (Appendix E). Allowing for replacement in the matching algorithm does not meaningfully alter the general conclusions from the irrigation models (Appendix E).

Overall, the irrigation model estimates provide mixed support for the notion that the tax break brought about by the UVA policy led to a higher rate of irrigation in Kansas. The Colorado border segment provides evidence consistent with this potential outcome of UVA, but we cannot rule out that some of the UVA effects may derive from differences in plot characteristics which made Kansas farmland more suitable for irrigation. We noted previously the similarity of farmland tax policies in Kansas and Colorado. In addition, the institutions governing groundwater use are also quite similar between the two states. Both states rely on the prior appropriation doctrine to administer groundwater pumping rights. It is plausible that some minor policy changes in the later portion of our study period may have influenced the irrigation model results, but, on the whole, Colorado is likely the best control state for the irrigation model, particularly for 1997 and earlier.<sup>27</sup> On balance, the irrigation results for the Colorado border segment provide suggestive evidence, at best, that farmers reinvested the tax savings brought about by the UVA program in the form of more irrigation at the extensive margin.

Results for Nebraska provide no support for the notion that the UVA policy led to more irrigation in Kansas. Nebraska, however, is perhaps the worst control group of the three bordering states. In addition to having a far different program for assessing farmland taxes, Nebraska relies on a correlative rights program to administer groundwater rights, which essentially ties them to the ownership of land overlying the aquifer, as opposed to seniority.<sup>28</sup> Oklahoma also relies on a correlative rights system, but has a farmland tax policy which is similar in spirit to that of Kansas. For the Oklahoma border segment, the results are the least consistent, and suggest that the UVA policy may have led to an immediate relative decline in irrigation in Kansas, but led to a longer term increase in irrigated land throughout

the broader border-segment area.

## **Discussion and Conclusions**

This study examines two possible outcomes of use-value assessment, arguably the most widespread form of land-use regulation in the United States. Under UVA, farmland is taxed according to its value in perpetual agricultural use, as opposed to its full market value which reflects returns to converting the land to other uses, such as residential housing. UVA is intended to reduce farmland owners' incentives to develop land, but, despite its ubiquity, there is little rigorous empirical evidence of its effect on land-use decisions. This is largely due to the fact that most policies were implemented decades ago, when data and methods necessary to study their effects were not well developed. Relying on a combination of matching and difference-in-differences analysis using plot-level panel data, our application exploits the spatial-temporal discontinuity in UVA adoption between Kansas and neighboring states. The estimated UVA effects provide fairly strong and robust evidence that the UVA policy reduced development likelihood on the Kansas side of the border of the greater Kansas City area. The estimated effects dissipate over time, which is consistent with the notion that UVA policies provide a temporary incentive to, at most, delay development (Hellerstein et al., 2002). In other words, our results are consistent with the idea that property tax incentives provide a meaningful lever to influence land-use decisions for a time, but returns to development will eventually be sufficiently large such that the opportunity cost of not developing is no longer justifiable on financial grounds. The fact that the development effects do not emerge until 2002 is consistent with the notion that there are large option values associated with development decisions, and that it took landowners time to update their expectations in response to the new tax policy.

Some proponents of preferential taxation have argued that the smaller and more predictable tax burden brought about by UVA may encourage farmers to make additional investments in their operation. To this end, we examined the degree to which UVA increases farm investment by looking at irrigation adoption in western Kansas. Overall, our results to this end are mixed, with the most consistent results emerging for the Kansas-Colorado

border. While having the financial means to irrigate is likely viewed as a positive from the perspective of farmers, there also may be external costs associated with increasing the extensive margin of irrigation. The increased mining of the Ogallala Aquifer, along with potential policy responses, is a topic that has received considerable attention from both natural scientists and economists (see, e.g., Scanlon et al., 2012; Lin Lawell, 2016). The irrigation adoption results, however, are not definitive in this regard. For the Colorado border segment, we are unable to conclude that the bulk of the effects are not attributable to differences in the attributes of Kansas and Colorado farmland. Of course, irrigation is not the only investment possibility for landowners affected by the policy. Other possibilities include crop switching, adoption of improved technology (e.g., drought-tolerant corn), land acquisition, and alternative investments unrelated to farming.

Ultimately, our study indicates that tax incentives can have an impact on parcel-level land-use decisions, and our findings carry a number of policy implications. Preferential farmland taxation policies are not without criticism. To some extent, this controversy stems from the distributional consequences of shifting a portion of the local tax base from farmland owners to other landowners within a tax assessment jurisdiction (Anderson and Griffing, 2000). If farmers are investing a portion of their tax savings back into their operation through irrigation or other land improvements, the additional revenue growth provided by these investments could partly dampen the magnitude of the shift in the tax base. For example, irrigated land generally yields higher tax revenues than nonirrigated land, thus reducing the loss of total tax revenue from farmland after the adoption of UVA. However, our results provide suggestive evidence, at best, that this may be occurring. While it does appear that the UVA policy reduced the incentives of farmers to develop their land, it is unlikely that accomplishing this through a large statewide property tax break is justifiable from a social cost-benefit standpoint. From a broader research perspective, preferential farmland tax policy is an understudied topic and there remain numerous aspects that could be studied in greater detail, including these broader impacts on local public financing, public goods provision, and investment.

# Notes

<sup>1</sup>Most states also have similar provisions for forested land (Anderson, 2012).

<sup>2</sup>Anderson and England (2014) provide a comprehensive review of the history and characteristics of preferential farmland taxation, including a description of how policies work in each state.

<sup>3</sup>Apart from Wisconsin, which adopted its policy in 1995, Wyoming is the only other state with an adoption year (1989) as recent as that of Kansas (Anderson, Giertz, and Shimul, 2015).

<sup>4</sup>Historical information on tax rates in Kansas was obtained through personal communication with the Kansas Department of Revenue.

<sup>5</sup>Another noteworthy feature of Kansas's UVA policy is the absence of a development penalty. In some states with UVA, penalties in the form of repayment of foregone tax revenues are levied on land that is subject to preferential taxation and then subsequently developed. Development penalties are also not present in the policies of the states neighboring Kansas.

<sup>6</sup>In Missouri, net operating income measures are taken as a ten-year rolling average, and vary with land use, crop choice, and soil productivity. The net income measures are translated into a use value using the ten-year moving average of the farm real estate interest rate reported by the Federal Reserve Bank of Kansas City. Although the Food and Agricultural Policy Research Institute (2007) notes that farmland assessments were based on a fixed market-value assessment ratio before 1985, farmland tax rates fell precipitously in Missouri after 1975 at a time when farmland values in Missouri were rising faster than in any other study area state (U.S. Department of Agriculture, 2014). This suggests that the 1975 legislation did lead to a divergence between farmland taxes and market conditions.

<sup>7</sup>According to the USDA National Resources Inventory data used in this paper, roughly

90% of irrigated land in our western Kansas study area is irrigated with groundwater.

<sup>8</sup>The use-value format used for agricultural land taxation in Colorado has changed little over time, with the only major change taking place in 2012, when greater restrictions were placed on how the provisions were applied to homesteads and other farm-adjacent residential properties.

<sup>9</sup>For a detailed history of Nebraska’s farmland tax legislature, see Nebraska Department of Revenue (2017).

<sup>10</sup>The Census of Agriculture did not begin asking about property tax expenses until 1987.

<sup>11</sup>As shown in Appendix A, similar results are obtained if we split the sample based on the 50th percentile of the 1987 population density distribution.

<sup>12</sup>As a reviewer points out, however, it is possible that some of these characteristics could change endogenously with the use of irrigation. Likewise, producers may also switch the crops they grow when land is irrigated (e.g., corn over wheat), which implies a change to the relevant components of  $\mathbf{P}$  and  $\mathbf{Y}$  that enter the farmer’s observed production decisions.

<sup>13</sup>Relaxing this constraint would entail a dynamic formulation, similar to that given above for land development, which incorporates the investment in durable irrigation-related capital.

<sup>14</sup>Since Kansas passed the original UVA legislation in 1985, it is possible that our results are influenced by expectations regarding the eventual form of the policy. Our estimates can be considered conservative to the extent that any effects manifested prior to 1982. For example, if development in Kansas was artificially low in 1982 due to policy expectations, any further decline shown in our results would be smaller in magnitude than it would have been if not for the anticipated policy outcomes.

<sup>15</sup>This is analogous to the stacking strategy based on the county-level observations in Dube, Lester, and Reich (2010), where a county is included in the estimating dataset for as many times as it can be paired with a neighbor on the opposite side of the state border.

<sup>16</sup>See Ferraro and Miranda (2014); Chen, Lewis, and Weber (2016); Ferraro and Miranda (2017), among others, for recent applications of post-matching DD models.

<sup>17</sup>While matching without replacement has the advantage of yielding a balanced sample of treated and untreated observations, a downside is that the matches are not optimal and sensitive to the order in which the data are sorted (Dehejia and Wahba, 2002). In Appendices D and E, we show that estimating our main models using a sample matched with replacement produces similar results.

<sup>18</sup>NRI expansion factors are calibrated to match total land areas within each county, given by the most recent estimates from the U.S. Census Bureau, as well as other known control quantities (e.g., water areas and federal land). Importantly, each time the NRI is adjusted, weights are recalibrated to match historical land use patterns using a process known as iterative proportional scaling. For more information on how the NRI weights are constructed, see Nusser and Goebel (1997); Fuller (1999); Goebel (2009).

<sup>19</sup>According to USDA-NRCS, 2012, irrigated land in the NRI are defined as "Land that shows evidence of being irrigated during the year of the inventory or of having been irrigated during 2 or more of the last 4 years. Water is supplied to crops by ditches, pipes, or other conduits. For the purposes of the NRI, water spreading is not considered irrigation."

<sup>20</sup>As a reviewer points out, one potentially important factor we do not observe is elevation, which may be particularly relevant for the wide bandwidths along the Colorado border segment. Since Colorado is, in general, at a higher elevation than Kansas, the aggregate difference in elevation should be accounted for by the baseline Kansas effect,  $\alpha_S$ . To some extent, the other soil-related variables (wind and water erosion and slope) should further proxy for elevation patterns within each state.

<sup>21</sup>Development changes for the different bandwidths (5, 10, 15, 20, and 25 miles) are provided in Appendix B. With few exceptions, the trends described here for the full samples are similar for the subsamples contained within each border bandwidth.

<sup>22</sup>In addition to the plot characteristics included in the development and irrigation models, the propensity score logit models also include the NRI expansion factor as an additional covariate to control for plot size. The logit models themselves, however, are not weighted. Results from the propensity score models are given in Appendix C. Mean values of the development model county attributes for Kansas and Missouri are also presented in Appendix C.

<sup>23</sup>NMD figures for the other bandwidths are presented in Appendix C.

<sup>24</sup>Irrigated acreage changes for the other bandwidths are presented in Appendix B.

<sup>25</sup>According to county-level data from the Census of Agriculture, the Colorado counties in the study area saw a 13% net decline in irrigation over the 1982-2012 period, Nebraska counties saw an increase of 23%, and the Oklahoma counties saw a 2% decline. The Kansas counties along the Colorado, Nebraska, and Oklahoma border segments were subject to net changes of -11%, 9%, and 31%, respectively. Thus, from an aggregate standpoint, the Colorado border segment samples most closely match one another in terms of aggregate irrigated acreage change over the study period.

<sup>26</sup>See Appendix C for the irrigation sample NMDs for alternative bandwidths. Note that the dummy variable for flood potential drops out of the matched 5-mile Oklahoma sample due to perfect collinearity. State-level mean values of the county attributes included in the irrigation adoption models are also presented in Appendix C.

<sup>27</sup>The other policy changes include local incentives for high-efficiency drop nozzle sprinklers in Kansas brought about through federal and local state initiatives starting in 1998 (Pfeiffer and Lin, 2014), though the federal program was likely also available to Colorado farmers. Moreover, our summary statistics indicate that irrigated area actually dropped more in Kansas than Colorado after 1992 (table 1). There was, however, a small water rights retirement program which went into place in Colorado in 2006 may have partly contributed to this decline (Monger et al., 2018).

<sup>28</sup>Nebraska's groundwater institutions have also undergone a number of relatively recent changes related to groundwater conservation policy. For the Republican River Basin, the area adjacent to western Kansas, regulation timing varied, with some natural resource districts adopting volumetric irrigation as recently as 2004.

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# Figures

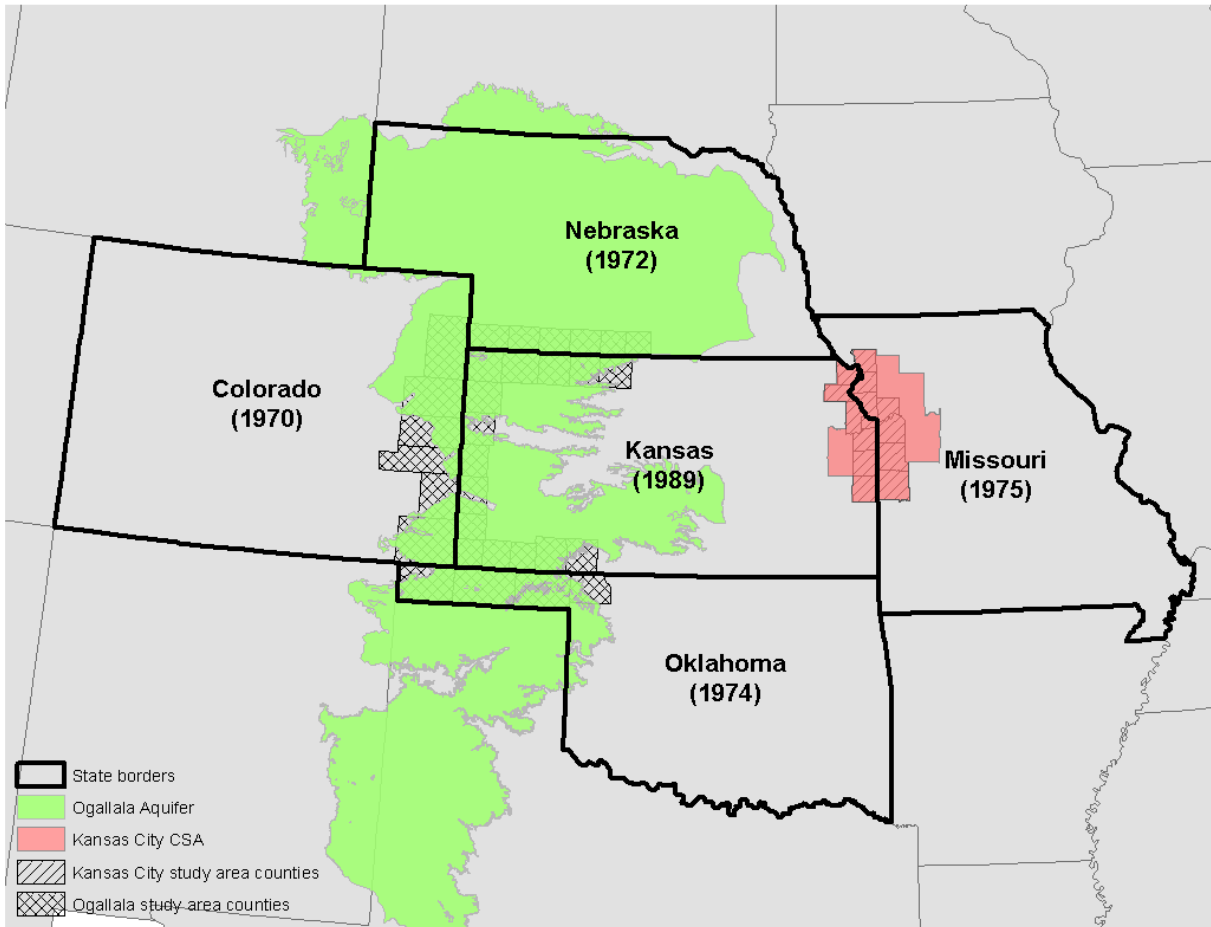


Figure 1. Kansas City Combined Statistical Area and Ogallala Aquifer

Note: The polygons with the lattice overlay represent the counties included in our samples. In parentheses under each state name is the year in which the state adopted its original use-value assessment policy.

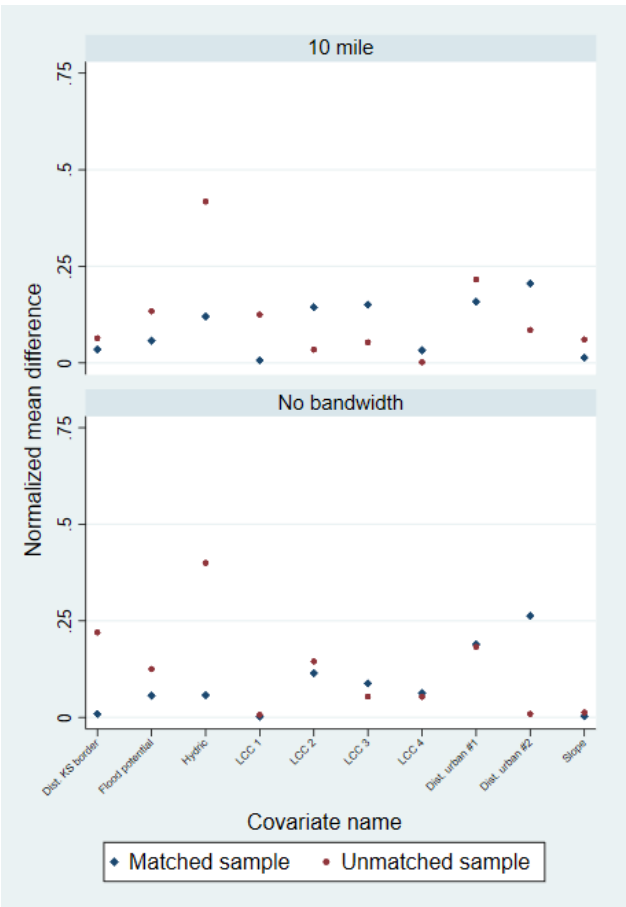


Figure 2. Normalized mean differences in plot covariates for Kansas City CSA development model sample, 10-mile bandwidth and full sample

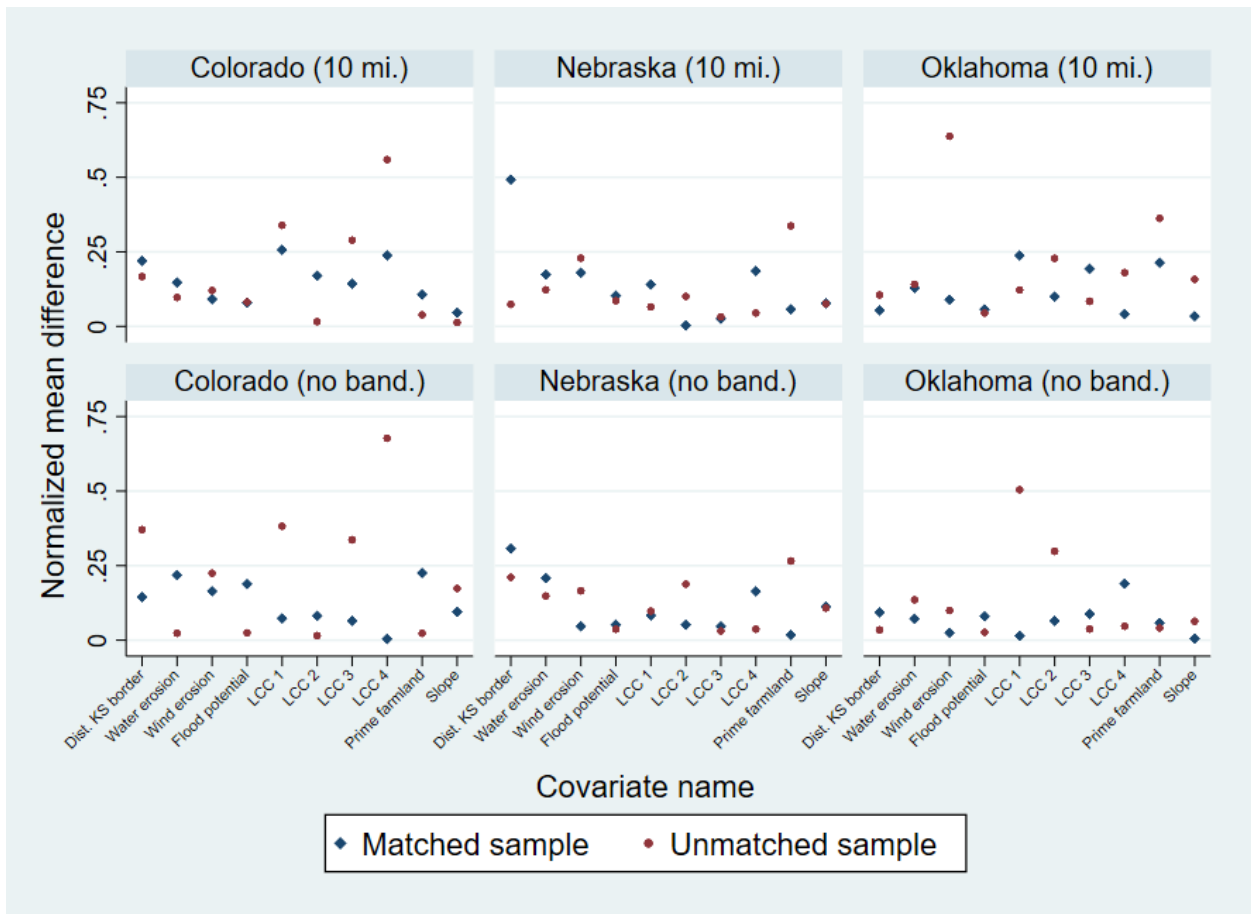


Figure 3. Normalized mean differences in plot covariates for 10-mile bandwidth and full county samples, irrigation model border segments

## Tables

Table 1. Changes in Outcome Variables, by Treatment and Control Group, Full Samples

Five-year period ending:	1987	1992	1997	2002	2007	2012	Total
Development:							
KS	2.2	15.8	20.9	13.3	8.0	2.6	62.8
MO	20.0	11.5	31.3	21.0	10.9	6.6	101.3
Irrigation, Colorado segment:							
KS	-7.2	5.7	-12.6	-49.1	-5.3	-6.8	-75.3
CO	-20.5	-42.5	14.7	-14.1	4.2	-38.7	-96.9
Irrigation, Nebraska segment:							
KS	-0.8	13.8	12.3	-10.8	2.1	-0.8	15.8
NE	39.0	8.5	19.2	25.9	9.1	-3.4	98.3
Irrigation, Oklahoma segment:							
KS	-2.0	-7.2	11.7	15.9	4.4	2.7	25.5
OK	11.0	10.7	-9.6	-30.5	4.9	-13.0	-26.5

Table 2. Effect of Use-Value Assessment on Various Farmland Tax Variables, 1987-1992

Variable	All counties	Rural counties	Urban counties
Log(Farmland property tax)	-0.133 (0.025)*** [-12.49]	-0.145 (0.030)*** [-13.52]	-0.093 (0.030)*** [-8.94]
Log(Farmland property tax per acre)	-0.146 (0.028)*** [-13.62]	-0.157 (0.032)*** [-14.55]	-0.106 (0.037)*** [-10.15]
Log(Farmland property tax per farm)	-0.123 (0.029)*** [-11.57]	-0.131 (0.034)*** [-12.34]	-0.093 (0.040)** [-8.96]
Log(Effective farmland property tax rate)	-0.128 (0.042)*** [-12.10]	-0.140 (0.050)*** [-13.16]	-0.094 (0.060) [-9.14]
Observations	886	664	222
Counties	443	332	111

Notes: These results were generated from a regression of the various variables listed in the leftmost column on a set of county fixed effects, a 1992 dummy variable, and an interaction between the 1992 dummy variable and a dummy variable denoting counties in Kansas. The interaction term coefficients represent the effects of the use-value assessment policy and are reported in the above table. Standard errors, reported in parentheses, are clustered by USDA agricultural district. The bracketed terms represent the marginal effect of the UVA policy in percentage terms. Urban and rural counties were determined based on the 75th percentile of the 1987 distribution of population density.

Table 3. Land Development Model, UVA Effect Estimates by Year and Bandwidth, Matched Sample

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.042 (0.016)***	-0.014 (0.005)***	-0.018 (0.005)***	-0.020 (0.005)***	-0.015 (0.004)***	-0.012 (0.003)***
1992	-0.013 (0.016)	<0.001 (0.007)	-0.005 (0.007)	-0.008 (0.006)	-0.007 (0.005)	-0.006 (0.005)
1997	0.006 (0.009)	0.007 (0.009)	-0.007 (0.009)	-0.001 (0.008)	-0.010 (0.007)	-0.007 (0.006)
2002	-0.034 (0.012)***	-0.024 (0.009)***	-0.024 (0.007)***	-0.019 (0.005)***	-0.020 (0.005)***	-0.018 (0.004)***
2007	-0.020 (0.008)**	-0.013 (0.004)***	-0.018 (0.004)***	-0.013 (0.003)***	-0.012 (0.003)***	-0.011 (0.003)***
2012	-0.027 (0.013)**	-0.018 (0.006)***	-0.019 (0.005)***	-0.013 (0.004)***	-0.010 (0.003)***	-0.009 (0.003)***
No. observations	2,420	5,994	8,872	10,782	12,500	12,758
No. plots (w/ repeats)	386	936	1,384	1,676	1,922	1,954
No. plots (no repeats)	263	631	908	1,120	1,280	1,307

Notes: The dependent variable in the above models is binary and takes a value of 1 once a plot is developed, at which point it is removed from the sample. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table 4. Irrigation Model, UVA Effect Estimates by Year, Border Segment, and Bandwidth, Matched Sample

Segment: Bandwidth (mi.):	Colorado			Nebraska			Oklahoma		
	10	20	None	10	20	None	10	20	None
1987	0.032 (0.021)	0.016 (0.013)	0.018 (0.010)*	-0.017 (0.011)	-0.021 (0.013)	-0.018 (0.009)**	-0.012 (0.011)	-0.020 (0.010)**	-0.010 (0.005)*
1992	0.075 (0.024)***	0.039 (0.016)**	0.031 (0.013)**	-0.002 (0.015)	-0.040 (0.020)**	-0.019 (0.012)	-0.027 (0.020)	-0.025 (0.016)	-0.015 (0.013)
1997	0.041 (0.032)	0.039 (0.020)*	0.034 (0.018)*	-0.002 (0.015)	-0.071 (0.023)***	-0.031 (0.013)**	-0.009 (0.027)	-0.027 (0.019)	0.023 (0.023)
2002	0.044 (0.029)	0.053 (0.020)**	0.027 (0.019)	-0.017 (0.017)	-0.100 (0.025)***	-0.056 (0.016)***	0.027 (0.041)	-0.005 (0.032)	0.061 (0.027)**
2007	0.048 (0.030)	0.040 (0.021)*	0.022 (0.019)	-0.033 (0.027)	-0.108 (0.030)***	-0.067 (0.020)***	0.044 (0.041)	0.011 (0.033)	0.056 (0.023)**
2012	0.036 (0.031)	0.042 (0.021)**	0.029 (0.020)	-0.037 (0.027)	-0.108 (0.030)***	-0.071 (0.021)***	0.080 (0.038)**	0.028 (0.031)	0.073 (0.027)***
No. observations	2,898	5,460	7,854	2,359	4,466	9,772	2,583	5,173	10,304
No. plots (w/ repeats)	414	780	1,122	337	638	1,396	369	739	1,472
No. plots (no repeats)	277	513	740	233	418	848	277	510	931

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

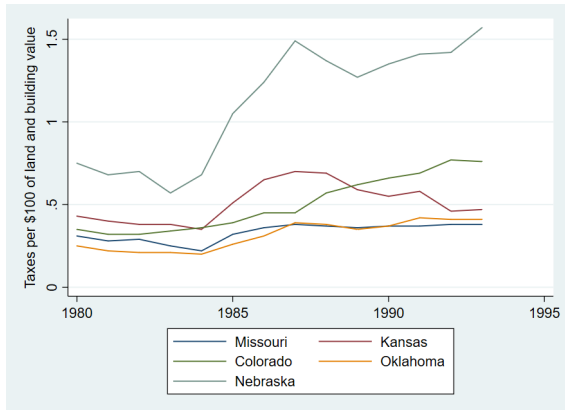
Title: "AJAE appendix for A Tale of Two Borders: Use-Value Assessment, Land Development, and Irrigation Investment"

Authors: Daniel P. Bigelow and Todd Kuethe

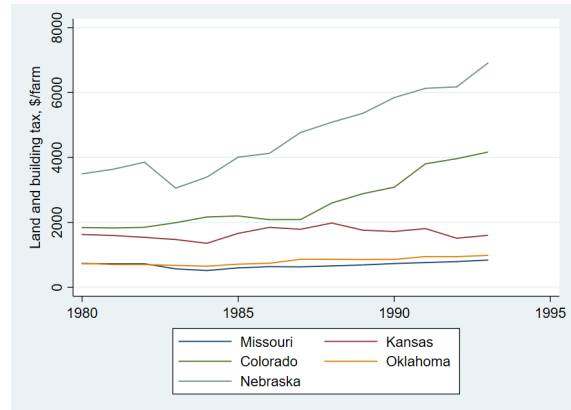
Date: February 11, 2020

Note: The material contained herein is supplementary to the article named in the title and published in the American Journal of Agricultural Economics (AJAE).

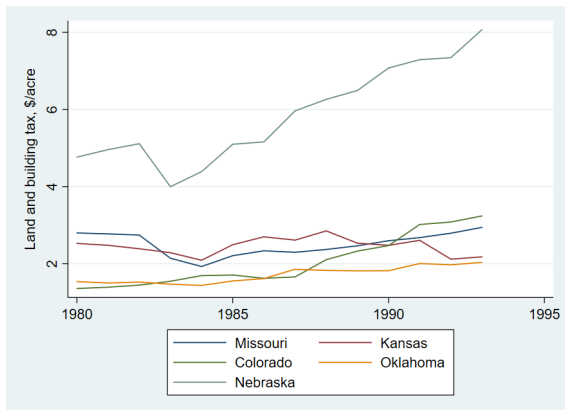
# Appendix A



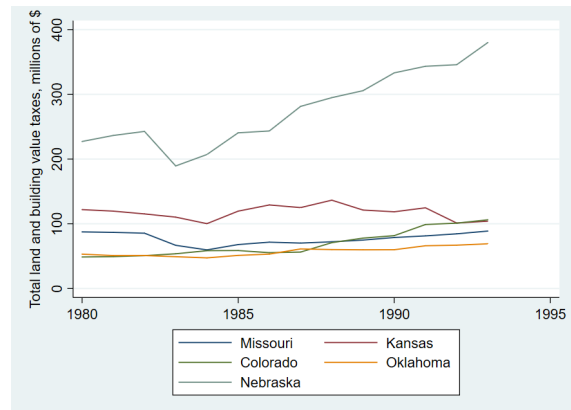
(a) Farm real estate taxes per \$100 of farm real estate value (effective tax rate)



(b) Farm real estate tax expenses per farm



(c) Farm real estate tax expenses per acre



(d) Total farm real estate tax expenses

Figure A1. State-level trends in farm real estate value taxation, 1980-1993

Table A1. Effect of Use-Value Assessment on Various Farmland Tax Variables, 1987-1992, Alternative Estimates

Variable	<i>Weighted by farmland acreage</i>			<i>Alternative rural and urban split</i>		
	All counties	Rural counties	Urban counties	Rural counties	Urban counties	Urban counties
Log (Farmland property tax)	-0.131 (0.028)*** [-12.27]	-0.136 (0.033)*** [-12.79]	-0.100 (0.030)*** [-9.57]	-0.142 (0.035)*** [-13.33]	-0.114 (0.028)*** [-10.84]	
Log (Farmland property tax per acre)	-0.140 (0.031)*** [-13.07]	-0.144 (0.036)*** [-13.46]	-0.114 (0.035)*** [-10.82]	-0.153 (0.037)*** [-14.26]	-0.131 (0.029)*** [-12.28]	
Log (Farmland property tax per farm)	-0.114 (0.034)*** [-10.82]	-0.119 (0.038)*** [-11.26]	-0.092 (0.045)* [-8.84]	-0.135 (0.039)*** [-12.74]	-0.104 (0.030)*** [-9.9]	
Log (Effective farmland property tax rate)	-0.157 (0.054)*** [-14.69]	-0.169 (0.062)*** [-15.72]	-0.107 (0.058)* [-10.33]	-0.163 (0.063)** [-15.19]	-0.087 (0.046)* [-8.44]	
Observations	886	664	222	442	444	
Counties	443	332	111	221	222	

Notes: These results were generated from a regression of the various variables listed in the leftmost column on a set of county fixed effects, a 1992 dummy variable, and an interaction between the 1992 dummy variable and a dummy variable denoting counties in Kansas. In the first three columns, all observations are weighted by the acreage of farmland in the county reported for 1987. The interaction term coefficients represent the effects of the use-value assessment policy and are reported in the above table. Standard errors, reported in parentheses, are clustered by USDA agricultural district. The bracketed terms represent the marginal effect of the UVA policy in percentage terms. Urban and rural counties were determined based on the 75th percentile of the 1987 population density distribution. In the final two columns, the urban and rural counties are designated by the 50th, rather than the 75th percentile of the 1987 population density distribution.

## Appendix B

Table B1. NRI Changes in Developed Acreage (1000s) in Kansas City CSA by Bandwidth

Five-year period ending:	1987	1992	1997	2002	2007	2012	Total
<u>5-mile bandwidth</u>							
KS	0.5	5.0	4.2	1.6	1.7	0.7	13.7
MO	5.4	4.5	1.3	2.4	0.9	2.2	16.7
<u>10-mile bandwidth</u>							
KS	1.9	10.4	14.0	8.8	4.8	1.5	41.4
MO	9.2	5.5	10.7	11.5	6.5	5.2	48.6
<u>15-mile bandwidth</u>							
KS	2.1	13.0	18.2	10.7	6.1	1.9	52.0
MO	13.2	8.6	19.0	15.1	8.2	5.9	70.0
<u>20-mile bandwidth</u>							
KS	2.1	15.5	20.2	12.7	7.7	2.4	60.6
MO	19.8	10.4	28.5	18.9	10.4	6.5	94.5
<u>25-mile bandwidth</u>							
KS	2.2	15.8	20.9	13.3	8.0	2.6	62.8
MO	20.0	11.5	30.0	21.0	10.9	6.6	100.0

Table B2. NRI Changes in Irrigated Acreage (1000s) by Bandwidth, Colorado Border Segment

Five-year period ending:	1987	1992	1997	2002	2007	2012	Total
<u>5-mile bandwidth</u>							
KS	0.0	16.0	-4.4	-0.9	0.0	0.0	10.7
CO	-14.0	-4.4	11.0	-7.9	-2.9	-2.9	-21.1
<u>10-mile bandwidth</u>							
KS	1.3	17.3	-14.6	-7.0	-5.8	0.0	-8.8
CO	-21.6	-9.4	22.7	-11.6	-9.6	-2.9	-32.4
<u>15-mile bandwidth</u>							
KS	1.3	11.7	-12.1	-13.2	-5.6	0.0	-17.9
CO	-17.1	-34.6	16.5	-19.4	-5.1	-24.4	-84.1
<u>20-mile bandwidth</u>							
KS	1.3	10.7	-14.5	-50.4	-8.6	-1.0	-62.5
CO	-15.3	-35.6	1.3	-33.4	-0.1	-14.4	-97.5
<u>25-mile bandwidth</u>							
KS	1.3	10.4	-19.4	-54.5	-5.3	-6.8	-74.3
CO	-15.3	-40.0	7.1	-34.8	-3.4	-14.4	-100.8

Table B3. NRI Changes in Irrigated Acreage (1000s) by Bandwidth, Nebraska Border Segment

Five-year period ending:	1987	1992	1997	2002	2007	2012	Total
<u>5-mile bandwidth</u>							
KS	-0.8	4.1	3.4	-6.7	2.5	0.0	2.5
NE	-0.3	-2.8	2.8	1.4	-0.7	2.7	3.1
<u>10-mile bandwidth</u>							
KS	-0.8	4.1	3.4	-6.7	-1.2	0.0	-1.2
NE	5.4	-4.0	-0.8	0.0	3.9	2.8	7.3
<u>15-mile bandwidth</u>							
KS	-0.8	4.1	3.4	-6.7	-1.2	0.0	-1.2
NE	16.0	-4.9	10.0	11.5	5.7	2.8	41.1
<u>20-mile bandwidth</u>							
KS	-0.8	4.1	3.4	-2.1	2.1	0.0	6.7
NE	30.5	7.1	10.8	22.1	11.7	-3.6	78.6
<u>25-mile bandwidth</u>							
KS	-0.8	7.5	7.3	-7.2	2.1	0.0	8.9
NE	39.0	8.5	19.2	25.9	9.1	-3.4	98.3

Table B4. NRI Changes in Irrigated Acreage (1000s) by Bandwidth, Oklahoma Border Segment

Five-year period ending:	1987	1992	1997	2002	2007	2012	Total
<u>5-mile bandwidth</u>							
KS	1.3	1.8	8.9	-0.5	-0.2	2.5	13.8
OK	2.0	8.3	4.3	-8.9	-2.0	-4.2	-0.5
<u>10-mile bandwidth</u>							
KS	1.3	3.0	18.6	35.1	2.0	3.7	63.7
OK	3.7	15.8	4.3	-9.4	2.5	-4.5	12.4
<u>15-mile bandwidth</u>							
KS	1.3	4.1	24.3	33.8	3.1	3.7	70.3
OK	9.0	11.4	4.3	-2.7	-4.2	-4.5	13.3
<u>20-mile bandwidth</u>							
KS	1.3	2.1	20.4	33.5	1.4	2.7	61.4
OK	9.0	11.4	6.3	-3.8	-4.2	-4.5	14.2
<u>25-mile bandwidth</u>							
KS	-2.0	-5.6	17.0	21.5	0.5	2.7	34.1
OK	9.0	9.1	6.0	-14.0	-6.2	-4.5	-0.6

# Appendix C

Additional balance plots and propensity score model results

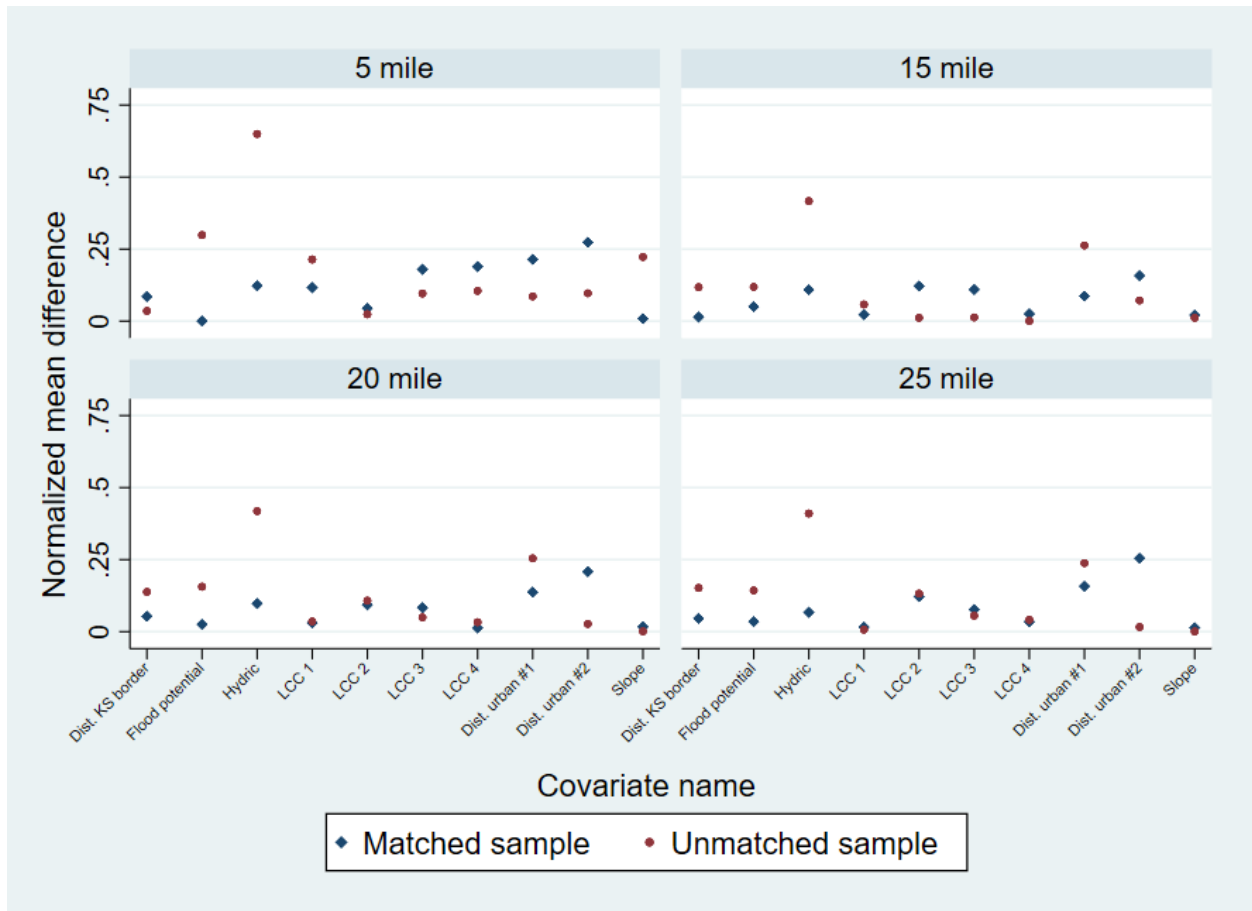


Figure C1. Normalized mean differences in plot covariates for Kansas City CSA development model sample, alternative bandwidths

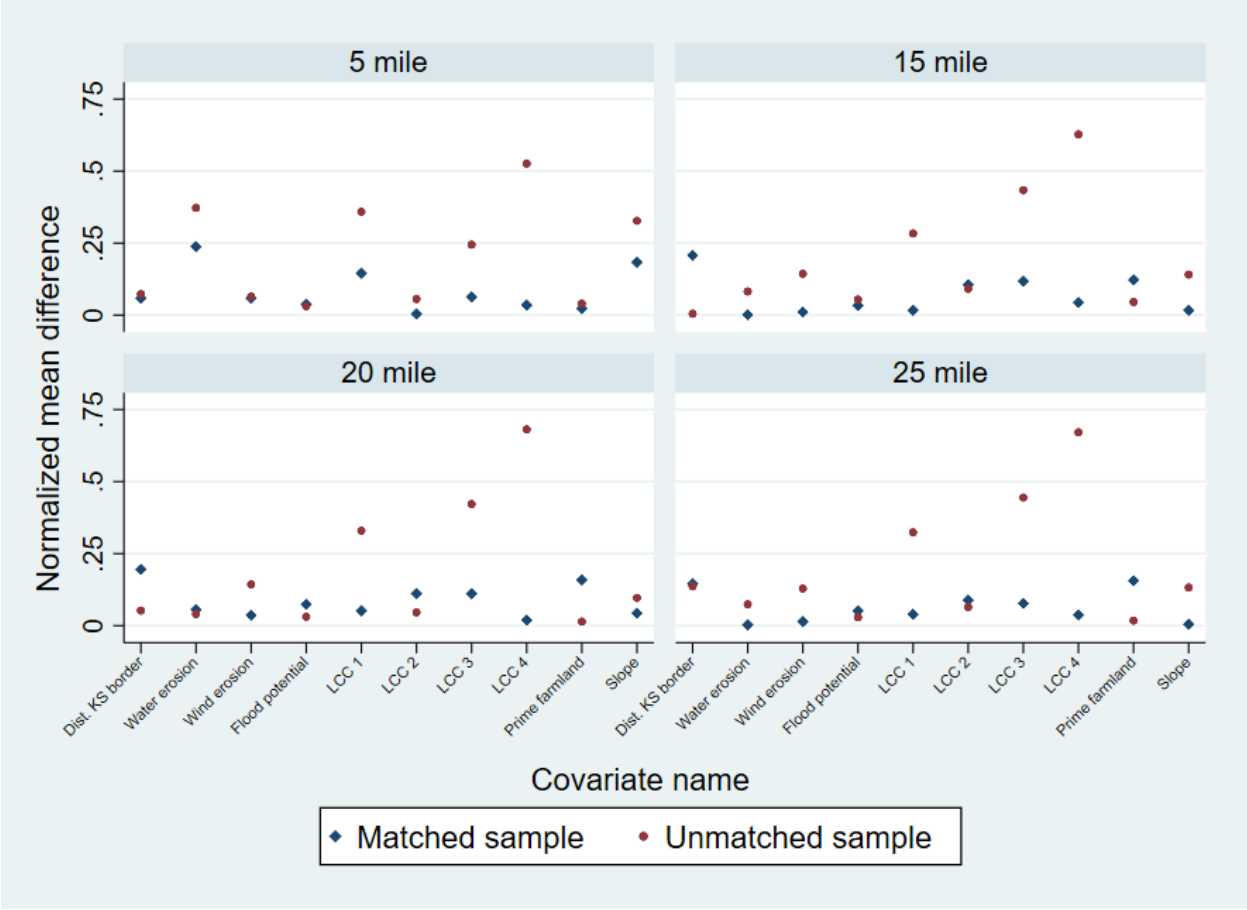


Figure C2. Normalized mean differences in plot covariates for alternative bandwidths, Colorado border segment

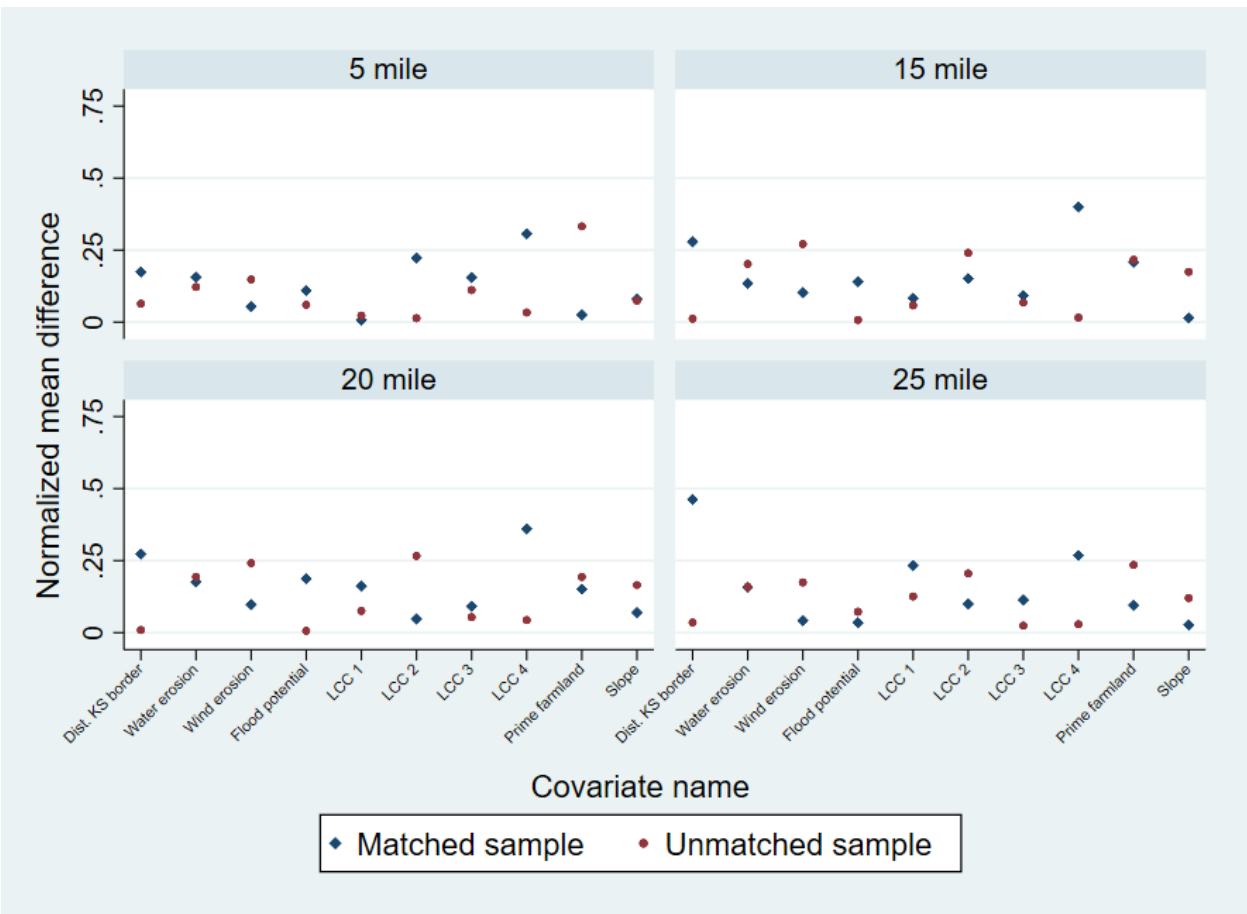


Figure C3. Normalized mean differences in plot covariates for alternative bandwidths, Nebraska border segment

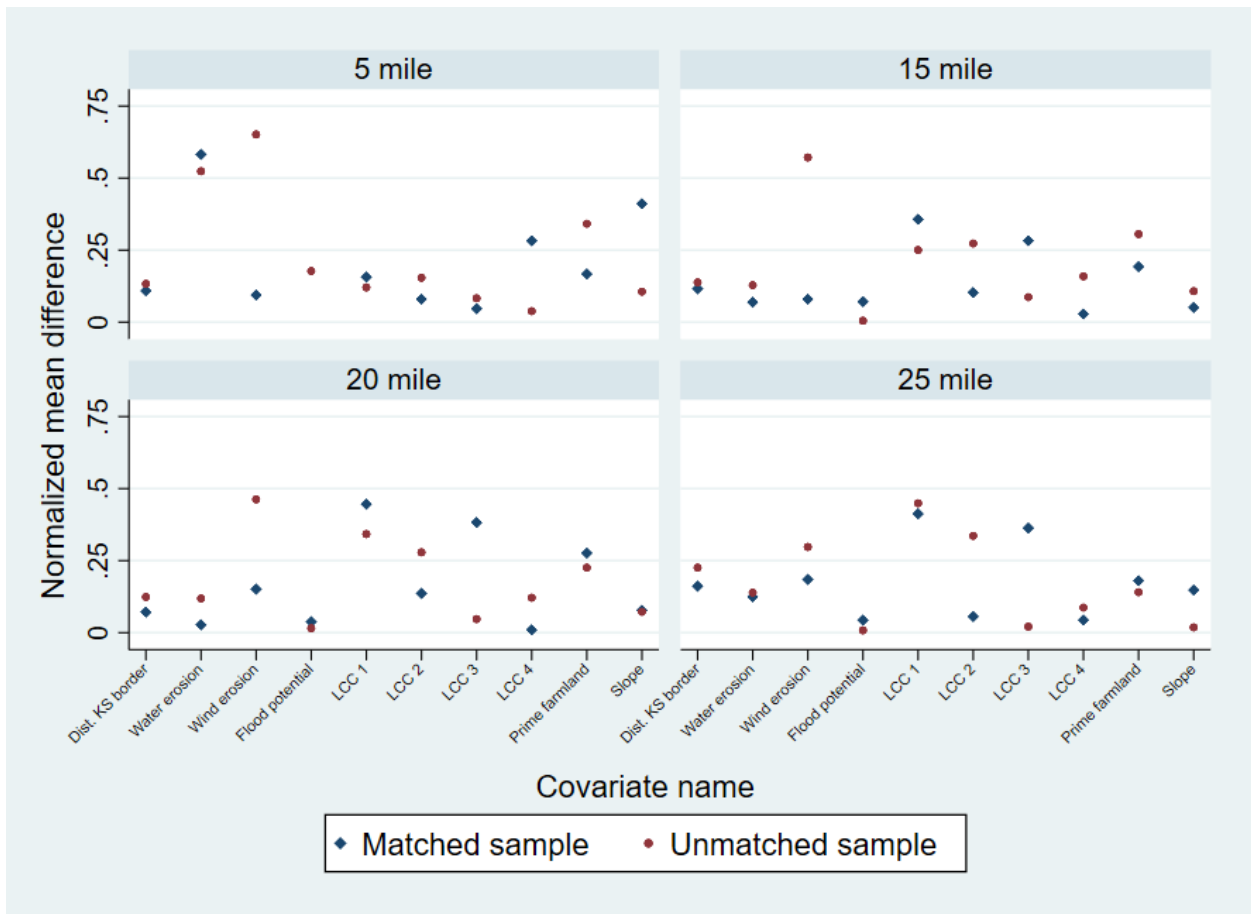


Figure C4. Normalized mean differences in plot covariates for alternative bandwidths, Oklahoma border segment

Table C1. Means of Baseline (1982) County Attributes Used in Development Models

	Kansas	Missouri
Farm real estate value (\$/acre)	1934	1953
Median household income (\$1000s)	39.11	38.07
Population (1000s)	53.00	69.64
Population density	0.21	0.20

Table C2. Means of Baseline (1982) County Attributes Used in Irrigation Models, by Border Segment

	Colorado		Nebraska		Oklahoma	
	KS	CO	KS	NE	KS	OK
Farm real estate value (\$/acre)	993	682	995	1446	1018	811
Irrigated farmland share	0.12	0.09	0.02	0.14	0.16	0.07
Rented farmland share	0.49	0.37	0.47	0.45	0.57	0.46
Corporate-owned farmland share	0.06	0.04	0.00	0.06	0.09	0.10

Table C3. Propensity Score Logit Model Estimates, Development Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	0.916 (1.156)	-0.015 (0.722)	-0.169 (0.556)	-0.645 (0.489)	-0.554 (0.458)	-0.436 (0.445)
LCC 2	0.336 (0.387)	-0.309 (0.277)	-0.606 (0.247)**	-1.189 (0.222)***	-1.328 (0.207)***	-1.371 (0.206)***
LCC 3	0.554 (0.340)	0.344 (0.249)	-0.240 (0.220)	-0.635 (0.199)***	-0.675 (0.188)***	-0.683 (0.187)***
LCC 4	-0.151 (0.381)	0.433 (0.270)	-0.129 (0.231)	-0.396 (0.210)*	-0.449 (0.200)**	-0.449 (0.199)**
Slope	0.004 (0.023)	-0.027 (0.017)	-0.074 (0.016)***	-0.113 (0.015)***	-0.121 (0.014)***	-0.124 (0.014)***
Hydric soil	-3.779 (1.063)***	-2.364 (0.276)***	-2.392 (0.224)***	-2.203 (0.198)***	-2.196 (0.183)***	-2.201 (0.181)***
Flood potential	-0.685 (0.340)**	0.294 (0.228)	0.247 (0.197)	-0.018 (0.173)	0.049 (0.162)	0.074 (0.161)
Dist. nearest city	0.117 (0.034)***	0.188 (0.022)***	0.210 (0.019)***	0.193 (0.017)***	0.188 (0.016)***	0.181 (0.016)***
Dist. sec. nearest city	0.009 (0.029)	-0.018 (0.016)	-0.046 (0.014)***	-0.045 (0.013)***	-0.041 (0.012)***	-0.042 (0.012)***
Dist. KS border	-0.138 (0.079)*	-0.052 (0.025)**	-0.053 (0.014)***	-0.051 (0.010)***	-0.049 (0.008)***	-0.058 (0.007)***
Expansion factor	-0.179 (0.023)***	-0.168 (0.014)***	-0.173 (0.011)***	-0.161 (0.010)***	-0.161 (0.009)***	-0.164 (0.009)***
No. plots	595	1,330	1,912	2,393	2,709	2,770

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is located in Kansas. Results from these models are used to construct matched samples which form the basis for the main development estimates shown and discussed in the paper (see Table 3). Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1%(\*\*\*) levels

Table C4. Propensity Score Logit Model Estimates, Irrigation Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	3.989 (0.815)***	3.939 (0.508)***	4.056 (0.400)***	3.863 (0.321)***	3.466 (0.268)***	3.354 (0.238)***
LCC 2	2.259 (0.642)***	2.413 (0.421)***	2.513 (0.335)***	2.340 (0.270)***	1.883 (0.230)***	1.490 (0.200)***
LCC 3	1.563 (0.598)***	1.906 (0.388)***	2.320 (0.313)***	2.070 (0.247)***	1.853 (0.210)***	1.288 (0.182)***
LCC 4	0.002 (0.603)	0.435 (0.380)	0.579 (0.306)*	0.190 (0.246)	-0.116 (0.216)	-0.309 (0.191)
Prime farmland	-1.592 (0.301)***	-1.635 (0.195)***	-1.328 (0.151)***	-1.331 (0.134)***	-1.297 (0.116)***	-1.243 (0.100)***
Slope	0.126 (0.093)	0.174 (0.066)***	0.128 (0.052)**	0.122 (0.048)**	0.049 (0.043)	0.026 (0.037)
Flood potential	-0.424 (0.414)	-0.770 (0.281)***	-0.472 (0.225)**	-0.392 (0.196)**	-0.313 (0.171)*	-0.414 (0.159)***
Wind erosion	0.046 (0.016)***	0.043 (0.011)***	0.045 (0.009)***	0.050 (0.008)***	0.046 (0.007)***	0.014 (0.006)**
Water erosion	-0.031 (0.065)	-0.076 (0.043)*	-0.058 (0.034)*	-0.056 (0.031)*	-0.030 (0.028)	-0.015 (0.024)
Dist. KS border	0.028 (0.067)	0.066 (0.023)***	0.021 (0.012)*	0.008 (0.008)	0.018 (0.006)***	-0.013 (0.003)***
Expansion factor	0.005 (0.006)	0.007 (0.004)*	0.009 (0.004)**	0.010 (0.003)***	0.014 (0.003)***	0.001 (0.003)
No. plots	570	1,255	1,876	2,488	3,178	3,953

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is located in Kansas. Results from these models are used to construct matched samples which form the basis for the main development estimates shown and discussed in the paper (see Tables 4 and E1). Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels.

# Appendix D

Table D1. Land Development Model, Control Variable Estimates by Year and Bandwidth, Matched Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	-0.023 (0.010)**	-0.027 (0.008)***	-0.019 (0.012)	-0.013 (0.018)	-0.003 (0.007)	-0.005 (0.006)
LCC 2	-0.001 (0.009)	-0.002 (0.006)	-0.005 (0.006)	0.002 (0.006)	0.001 (0.004)	-0.001 (0.004)
LCC 3	-0.013 (0.008)*	-0.009 (0.005)*	-0.008 (0.005)	-0.001 (0.005)	-0.001 (0.004)	-0.004 (0.003)
LCC 4	-0.004 (0.013)	-0.013 (0.007)*	-0.010 (0.006)*	-0.004 (0.005)	-0.004 (0.004)	-0.007 (0.004)*
Slope	<0.001 (0.001)	-0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)
Hydric soil	-0.009 (0.012)	0.006 (0.007)	-0.003 (0.005)	0.007 (0.004)	0.006 (0.003)*	0.006 (0.003)*
Flood potential	0.002 (0.011)	-0.004 (0.007)	>-0.001 (0.005)	-0.008 (0.004)*	-0.006 (0.003)*	-0.007 (0.003)**
Dist. nearest city	-0.003 (0.001)***	-0.003 (<0.001)***	-0.002 (<0.001)***	-0.002 (<0.001)***	-0.002 (<0.001)***	-0.002 (<0.001)***
Dist. sec. nearest city	<0.001 (0.001)	0.001 (<0.001)***	0.001 (<0.001)	0.001 (<0.001)**	<0.001 (<0.001)	<0.001 (<0.001)
Dist. KS border	<0.001 (0.002)	-0.001 (<0.001)	-0.001 (<0.001)*	>-0.001 (<0.001)	>-0.001 (<0.001)***	>-0.001 (<0.001)***
Pop. density	0.005 (0.027)	-0.041 (0.021)*	-0.064 (0.017)***	-0.049 (0.016)***	-0.033 (0.015)**	-0.035 (0.013)***
Median income	0.002 (0.001)**	0.001 (<0.001)*	0.001 (<0.001)*	0.001 (<0.001)***	0.001 (<0.001)***	0.001 (<0.001)**
Population	<0.001 (<0.001)***	<0.001 (<0.001)***	<0.001 (<0.001)***	<0.001 (<0.001)***	<0.001 (<0.001)***	<0.001 (<0.001)***
Farm real est. value	>-0.001 (<0.001)**	<0.001 (<0.001)	>-0.001 (<0.001)	>-0.001 (<0.001)	>-0.001 (<0.001)**	>-0.001 (<0.001)**
No. observations	2,420	5,994	8,872	10,782	12,500	12,758
No. plots (w/ repeats)	386	936	1,384	1,676	1,922	1,954
No. plots (no repeats)	263	631	908	1,120	1,280	1,307

Notes: Control estimates displayed above correspond to the models used to produce the UVA effects in Table 3. The dependent variable in the above models is binary and takes a value of 1 once a plot is developed, at which point it is removed from the sample. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table D2. Land Development Model, UVA Effect Estimates by Year and Bandwidth, Unmatched Sample

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.016 (0.007)**	-0.008 (0.004)**	-0.008 (0.003)***	-0.010 (0.003)***	-0.008 (0.002)***	-0.007 (0.002)***
1992	<0.001 (0.009)	0.009 (0.005)*	0.008 (0.004)*	0.009 (0.004)**	0.009 (0.003)***	0.009 (0.003)***
1997	0.012 (0.007)	0.009 (0.008)	0.006 (0.006)	0.004 (0.005)	0.005 (0.005)	0.005 (0.005)
2002	-0.006 (0.005)	<0.001 (0.005)	0.001 (0.003)	0.001 (0.003)	0.002 (0.003)	0.002 (0.002)
2007	0.003 (0.003)	-0.001 (0.003)	>-0.001 (0.002)	<0.001 (0.002)	0.001 (0.002)	0.001 (0.001)
2012	-0.007 (0.004)*	-0.003 (0.002)	-0.001 (0.002)	-0.001 (0.001)	>-0.001 (0.001)	>-0.001 (0.001)
No. observations	7,567	16,194	22,764	28,273	32,079	32,864
No. plots (w/ repeats)	1,166	2,501	3,515	4,353	4,920	5,033
No. plots (no repeats)	595	1,330	1,912	2,393	2,709	2,770

Notes: The dependent variable in the above models is binary and takes a value of 1 once a plot is developed, at which point it is removed from the sample. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table D3. Land Development Model, UVA Effect Estimates by Year and Bandwidth, Matched Sample, Alternative Specification with Post-UVA Plot Attribute Interaction Terms

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.042 (0.016)**	-0.014 (0.005)***	-0.018 (0.005)***	-0.020 (0.005)***	-0.015 (0.004)***	-0.012 (0.003)***
1992	-0.013 (0.017)	-0.003 (0.008)	-0.007 (0.007)	-0.009 (0.006)	-0.009 (0.005)	-0.009 (0.006)
1997	0.006 (0.010)	0.005 (0.009)	-0.009 (0.009)	-0.002 (0.008)	-0.012 (0.007)*	-0.009 (0.006)
2002	-0.034 (0.013)**	-0.027 (0.009)***	-0.025 (0.007)***	-0.020 (0.006)***	-0.022 (0.005)***	-0.021 (0.004)***
2007	-0.020 (0.010)**	-0.016 (0.005)***	-0.020 (0.005)***	-0.014 (0.004)***	-0.014 (0.003)***	-0.014 (0.003)***
2012	-0.028 (0.016)*	-0.021 (0.007)***	-0.021 (0.005)***	-0.014 (0.004)***	-0.012 (0.003)***	-0.012 (0.003)***
No. observations	2,420	5,994	8,872	10,782	12,500	12,758
No. plots (w/ repeats)	386	936	1,384	1,676	1,922	1,954
No. plots (no repeats)	263	631	908	1,120	1,280	1,307

Notes: The dependent variable in the above models is binary and takes a value of 1 once a plot is developed, at which point it is removed from the sample. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1%(\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, controls representing plot characteristics and county attributes, and interaction variables between the controls and a post-1987 dummy variable.

Table D4. Land Development Model, UVA Effect Estimates by Year and Bandwidth, Matched Sample, Matching with Replacement

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.121 (0.057)**	-0.015 (0.007)**	-0.019 (0.007)***	-0.038 (0.012)***	-0.031 (0.012)**	-0.040 (0.015)***
1992	-0.113 (0.052)**	-0.032 (0.025)	-0.006 (0.011)	-0.023 (0.011)**	-0.015 (0.009)*	-0.011 (0.008)
1997	0.001 (0.011)	-0.014 (0.023)	-0.026 (0.027)	-0.013 (0.012)	-0.016 (0.010)	-0.018 (0.015)
2002	-0.090 (0.037)**	-0.092 (0.029)***	-0.062 (0.025)**	-0.057 (0.022)***	-0.043 (0.013)***	-0.050 (0.017)***
2007	-0.030 (0.015)**	-0.019 (0.008)**	-0.025 (0.010)**	-0.020 (0.008)**	-0.029 (0.011)***	-0.030 (0.013)**
2012	-0.024 (0.011)**	-0.011 (0.004)**	-0.023 (0.008)***	-0.013 (0.004)***	-0.010 (0.003)***	-0.011 (0.003)***
No. observations	5,123	11,665	16,167	18,878	21,435	21,889
No. plots (w/ repeats)	793	1,800	2,503	2,923	3,297	3,356
No. plots (no repeats)	477	1,051	1,504	1,812	2,031	2,049

Notes: The dependent variable in the above models is binary and takes a value of 1 once a plot is developed, at which point it is removed from the sample. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, controls representing plot characteristics and county attributes, and interaction variables between these terms and a post-1987 dummy variable.

# Appendix E

Table E1. Irrigation Model, UVA Effect Estimates by Year and Border Segment, Other Bandwidths, Matched Sample

Segment: Bandwidth (mi.):	Colorado			Nebraska			Oklahoma		
	5	15	25	5	15	25	5	15	25
1987	0.052 (0.026)**	0.028 (0.012)**	0.015 (0.011)	-0.009 (0.010)	-0.009 (0.008)	-0.011 (0.008)	>-0.001 (<0.001)	-0.012 (0.008)	-0.018 (0.008)**
1992	0.075 (0.033)**	0.051 (0.018)**	0.032 (0.014)**	-0.002 (0.012)	-0.013 (0.016)	-0.004 (0.014)	-0.034 (0.036)	-0.021 (0.016)	-0.021 (0.015)
1997	0.024 (0.053)	0.032 (0.023)	0.011 (0.021)	-0.002 (0.012)	-0.029 (0.019)	-0.022 (0.015)	-0.108 (0.061)*	-0.021 (0.020)	-0.021 (0.017)
2002	0.051 (0.045)	0.045 (0.023)**	0.018 (0.021)	0.015 (0.016)	-0.050 (0.022)**	-0.033 (0.018)*	-0.110 (0.083)	0.009 (0.029)	-0.009 (0.028)
2007	0.062 (0.043)	0.048 (0.023)**	0.008 (0.022)	0.020 (0.016)	-0.073 (0.031)**	-0.038 (0.024)	-0.091 (0.085)	0.021 (0.030)	0.003 (0.029)
2012	0.033 (0.047)	0.056 (0.023)**	0.001 (0.023)	0.020 (0.016)	-0.076 (0.031)**	-0.035 (0.024)	-0.045 (0.073)	0.044 (0.027)	0.016 (0.028)
No. observations	1,302	4,424	6,440	1,057	3,752	6,251	896	4,165	7,070
No. plots (w/ repeats)	186	632	920	151	536	893	128	595	1,010
No. plots (no repeats)	128	414	610	109	339	567	102	421	670

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E2. Irrigation Model, Colorado Border Segment, Control Variable Estimates by Year and Bandwidth, Matched Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	1.021 (0.226)***	0.780 (0.169)***	0.812 (0.115)***	0.726 (0.102)***	0.857 (0.098)***	0.810 (0.082)***
LCC 2	0.573 (0.158)***	0.459 (0.131)***	0.469 (0.090)***	0.418 (0.075)***	0.477 (0.077)***	0.443 (0.060)***
LCC 3	0.221 (0.154)	0.178 (0.112)	0.234 (0.072)***	0.207 (0.047)***	0.313 (0.064)***	0.314 (0.046)***
LCC 4	0.175 (0.149)	0.092 (0.093)	0.178 (0.066)***	0.123 (0.047)***	0.198 (0.059)***	0.167 (0.041)***
Prime farmland	0.281 (0.192)	0.425 (0.139)***	0.416 (0.086)***	0.474 (0.089)***	0.426 (0.076)***	0.471 (0.064)***
Slope	0.168 (0.053)***	0.055 (0.039)	0.068 (0.025)***	0.054 (0.020)***	0.049 (0.020)**	0.069 (0.021)***
Flood potential	0.035 (0.244)	0.053 (0.094)	0.136 (0.080)*	0.097 (0.063)	0.023 (0.047)	0.041 (0.048)
Wind erosion	0.017 (0.007)**	0.021 (0.004)***	0.019 (0.005)***	0.023 (0.004)***	0.021 (0.004)***	0.022 (0.004)***
Water erosion	-0.096 (0.054)*	-0.015 (0.039)	-0.016 (0.012)	-0.011 (0.011)	-0.007 (0.011)	-0.026 (0.015)*
Dist. KS border	-0.033 (0.021)	-0.014 (0.006)**	-0.007 (0.003)**	-0.005 (0.002)**	-0.004 (0.002)**	-0.002 (0.001)**
Shr. farmland irrig.	0.645 (0.621)	-0.077 (0.327)	-0.221 (0.346)	-0.618 (0.354)*	-0.356 (0.275)	-0.116 (0.344)
Shr. farmland rented	-0.696 (0.356)*	-0.567 (0.195)***	-0.444 (0.194)**	-0.329 (0.170)*	-0.313 (0.156)**	-0.213 (0.129)
Shr. farmland corp.	0.537 (0.655)	0.826 (0.436)*	0.702 (0.350)**	0.696 (0.274)**	1.265 (0.325)***	0.932 (0.296)***
Farm real est. value	>-0.001 (<0.001)	>-0.001 (<0.001)	>-0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)
No. observations	1,302	2,898	4,424	5,460	6,440	7,854
No. plots (w/ repeats)	186	414	632	780	920	1,122
No. plots (no repeats)	128	277	414	513	610	740

Notes: The estimates displayed above are for the control variables in the models used to produce the UVA effects in Tables 4 and E1. The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E3. Irrigation Model, Colorado Border Segment, UVA Effect Estimates by Year and Bandwidth, Unmatched Sample

Bandwidth (mi.)	5	10	15	20	25	None
1987	0.037 (0.016)**	0.029 (0.013)**	0.029 (0.012)**	0.020 (0.010)**	0.017 (0.008)**	0.011 (0.006)*
1992	0.079 (0.025)***	0.060 (0.016)***	0.043 (0.015)***	0.028 (0.012)**	0.025 (0.011)**	0.018 (0.008)**
1997	0.028 (0.042)	0.016 (0.021)	0.022 (0.019)	0.024 (0.016)	0.014 (0.015)	0.011 (0.011)
2002	0.071 (0.039)*	0.040 (0.022)*	0.040 (0.020)**	0.034 (0.018)*	0.022 (0.017)	0.005 (0.013)
2007	0.087 (0.036)**	0.052 (0.022)**	0.042 (0.021)**	0.032 (0.019)*	0.021 (0.017)	0.004 (0.013)
2012	0.090 (0.039)**	0.053 (0.023)**	0.053 (0.021)**	0.035 (0.019)*	0.023 (0.018)	0.013 (0.013)
No. observations	2,863	6,132	9,303	12,068	14,980	19,404
No. plots (w/ repeats)	409	876	1,329	1,724	2,140	2,772
No. plots (no repeats)	212	459	690	899	1,139	1,489

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E4. Irrigation Model, Colorado Border Segment, UVA Effect Estimates by Year and Bandwidth, Alternative Specification with Post-UVA Plot Attribute Interaction Terms

Bandwidth (mi.)	5	10	15	20	25	None
1987	0.053 (0.025)**	0.031 (0.021)	0.028 (0.012)**	0.015 (0.013)	0.015 (0.011)	0.017 (0.010)*
1992	0.055 (0.033)	0.057 (0.023)**	0.033 (0.019)*	0.026 (0.017)	0.016 (0.016)	0.027 (0.014)*
1997	0.003 (0.051)	0.023 (0.031)	0.015 (0.024)	0.026 (0.020)	-0.004 (0.020)	0.029 (0.019)
2002	0.030 (0.041)	0.026 (0.028)	0.028 (0.023)	0.040 (0.021)*	0.003 (0.021)	0.022 (0.020)
2007	0.041 (0.040)	0.030 (0.028)	0.032 (0.023)	0.027 (0.021)	-0.007 (0.022)	0.017 (0.020)
2012	0.012 (0.043)	0.018 (0.029)	0.040 (0.023)*	0.029 (0.021)	-0.014 (0.023)	0.025 (0.021)
No. observations	1,302	2,898	4,424	5,460	6,440	7,854
No. plots (w/ repeats)	186	414	632	780	920	1,122
No. plots (no repeats)	128	277	414	513	610	740

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes, and interaction variables between the controls and a post-1987 dummy variable.

Table E5. Irrigation Model, Colorado Border Segment, UVA Effect Estimates by Year and Bandwidth, Matching with Replacement

Bandwidth (mi.)	5	10	15	20	25	None
1987	0.030 (0.015)**	0.069 (0.036)*	0.040 (0.019)**	0.071 (0.044)	0.026 (0.022)	0.027 (0.026)
1992	0.053 (0.021)**	0.095 (0.036)**	0.047 (0.020)**	0.077 (0.044)*	0.033 (0.022)	0.034 (0.027)
1997	-0.062 (0.107)	0.080 (0.045)*	0.007 (0.012)	0.078 (0.046)*	0.002 (0.030)	0.053 (0.027)*
2002	0.018 (0.046)	0.084 (0.044)*	0.008 (0.014)	0.065 (0.049)	0.001 (0.030)	0.039 (0.028)
2007	0.024 (0.045)	0.085 (0.044)*	0.010 (0.015)	0.057 (0.049)	-0.006 (0.030)	0.036 (0.027)
2012	0.007 (0.046)	0.078 (0.044)*	0.012 (0.015)	0.065 (0.048)	-0.009 (0.030)	0.037 (0.028)
No. observations	1,575	4,088	5,943	7,637	10,066	10,458
No. plots (w/ repeats)	225	584	849	1,091	1,438	1,494
No. plots (no repeats)	152	359	521	669	879	976

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E6. Irrigation Model, Nebraska Border Segment, Control Variable Estimates by Year and Bandwidth, Matched Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	0.772 (0.201)***	0.714 (0.143)***	0.751 (0.118)***	0.654 (0.110)***	0.637 (0.088)***	0.670 (0.087)***
LCC 2	0.032 (0.056)	0.096 (0.055)*	0.104 (0.055)*	0.092 (0.061)	0.061 (0.052)	0.027 (0.051)
LCC 3	0.084 (0.104)	0.245 (0.099)**	0.084 (0.072)	0.132 (0.067)**	0.115 (0.064)*	0.089 (0.062)
LCC 4	-0.059 (0.034)*	-0.006 (0.043)	0.027 (0.043)	-0.011 (0.045)	0.017 (0.042)	0.019 (0.040)
Prime farmland	-0.042 (0.029)	-0.044 (0.053)	-0.009 (0.043)	-0.069 (0.047)	-0.032 (0.039)	0.040 (0.037)
Slope	-0.004 (0.012)	-0.003 (0.015)	0.016 (0.009)*	0.014 (0.010)	-0.003 (0.012)	<0.001 (0.009)
Flood potential	-0.032 (0.044)	0.002 (0.056)	0.018 (0.044)	0.046 (0.045)	0.059 (0.039)	0.005 (0.031)
Wind erosion	0.028 (0.011)**	0.053 (0.010)***	0.028 (0.006)***	0.023 (0.006)***	0.029 (0.006)***	0.034 (0.006)***
Water erosion	-0.005 (0.006)	-0.006 (0.007)	-0.009 (0.005)*	-0.008 (0.006)	-0.001 (0.006)	>-0.001 (0.005)
Dist. KS border	0.019 (0.010)*	0.011 (0.004)**	0.009 (0.003)***	0.004 (0.002)**	0.003 (0.001)**	0.003 (0.001)**
Shr. farmland irrig.	-0.575 (0.623)	-0.194 (1.555)	1.042 (1.387)	0.575 (1.362)	0.915 (1.145)	1.376 (1.161)
Shr. farmland rented	-1.197 (0.835)	-0.060 (0.975)	0.272 (1.090)	-1.843 (1.022)*	-0.298 (0.798)	-0.858 (0.708)
Shr. farmland corp.	-0.149 (0.548)	0.084 (0.583)	-0.625 (0.627)	-1.731 (0.604)***	-0.702 (0.504)	-0.948 (0.413)**
Farm real est. value	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)*	<0.001 (<0.001)*
No. observations	1,057	2,359	3,752	4,466	6,251	9,772
No. plots (w/ repeats)	151	337	536	638	893	1,396
No. plots (no repeats)	109	233	339	418	567	848

Notes: The estimates displayed above are for the control variables in the models used to produce the UVA effects in Tables 4 and E1. The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1%(\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E7. Irrigation Model, Nebraska Border Segment, UVA Effect Estimates by Year and Bandwidth, Unmatched Sample

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.003 (0.005)	-0.015 (0.008)*	-0.026 (0.009)***	-0.031 (0.009)***	-0.028 (0.007)***	-0.028 (0.007)***
1992	0.016 (0.025)	-0.005 (0.013)	-0.019 (0.012)	-0.037 (0.012)***	-0.031 (0.010)***	-0.028 (0.010)***
1997	0.011 (0.027)	>-0.001 (0.016)	-0.028 (0.014)**	-0.042 (0.013)***	-0.038 (0.011)***	-0.034 (0.011)***
2002	-0.002 (0.025)	-0.004 (0.016)	-0.044 (0.015)***	-0.062 (0.014)***	-0.059 (0.013)***	-0.055 (0.013)***
2007	0.013 (0.029)	-0.010 (0.023)	-0.055 (0.019)***	-0.076 (0.018)***	-0.069 (0.015)***	-0.065 (0.015)***
2012	-0.002 (0.032)	-0.017 (0.024)	-0.059 (0.020)***	-0.074 (0.018)***	-0.068 (0.016)***	-0.065 (0.016)***
No. observations	2,716	5,824	8,953	12,369	15,596	16,919
No. plots (w/ repeats)	388	832	1,279	1,767	2,228	2,417
No. plots (no repeats)	196	416	641	903	1,142	1,232

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E8. Irrigation Model, Nebraska Border Segment, UVA Effect Estimates by Year and Bandwidth, Alternative Specification with Post-UVA Plot Attribute Interaction Terms

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.009 (0.010)	-0.017 (0.011)	-0.009 (0.009)	-0.021 (0.013)	-0.011 (0.008)	-0.019 (0.009)**
1992	-0.005 (0.014)	0.008 (0.016)	>-0.001 (0.016)	-0.016 (0.018)	0.010 (0.014)	-0.018 (0.013)
1997	-0.005 (0.014)	0.008 (0.016)	-0.016 (0.018)	-0.046 (0.020)**	-0.008 (0.016)	-0.030 (0.014)**
2002	0.014 (0.017)	-0.007 (0.017)	-0.037 (0.020)*	-0.075 (0.021)***	-0.019 (0.017)	-0.055 (0.016)***
2007	0.019 (0.020)	-0.022 (0.024)	-0.060 (0.029)**	-0.083 (0.027)***	-0.024 (0.024)	-0.066 (0.020)***
2012	0.019 (0.020)	-0.027 (0.024)	-0.063 (0.029)**	-0.083 (0.027)***	-0.021 (0.024)	-0.070 (0.020)***
No. observations	1,057	2,359	3,752	4,466	6,251	9,772
No. plots (w/ repeats)	151	337	536	638	893	1,396
No. plots (no repeats)	109	233	339	418	567	848

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes, and interaction variables between the controls and a post-1987 dummy variable.

Table E9. Irrigation Model, Nebraska Border Segment, UVA Effect Estimates by Year and Bandwidth, Matching with Replacement

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.005 (0.005)	-0.020 (0.015)	0.011 (0.011)	-0.012 (0.010)	-0.001 (0.007)	-0.007 (0.008)
1992	0.002 (0.009)	-0.011 (0.016)	-0.033 (0.037)	-0.099 (0.063)	0.001 (0.011)	-0.003 (0.014)
1997	0.002 (0.009)	-0.011 (0.016)	-0.041 (0.037)	-0.120 (0.061)**	-0.068 (0.051)	-0.015 (0.013)
2002	0.009 (0.009)	-0.029 (0.025)	-0.070 (0.047)	-0.095 (0.067)	-0.069 (0.053)	-0.041 (0.014)***
2007	0.017 (0.013)	-0.065 (0.043)	-0.144 (0.073)**	-0.110 (0.072)	-0.095 (0.058)	-0.043 (0.016)***
2012	0.017 (0.013)	-0.068 (0.043)	-0.145 (0.073)**	-0.111 (0.072)	-0.094 (0.058)	-0.067 (0.026)**
No. observations	1,295	2,856	4,676	6,125	7,595	9,800
No. plots (w/ repeats)	185	408	668	875	1,085	1,400
No. plots (no repeats)	121	252	385	500	633	770

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E10. Irrigation Model, Oklahoma Border Segment, Control Variable Estimates by Year and Bandwidth, Matched Sample

Bandwidth (mi.)	5	10	15	20	25	None
LCC 1	0.735 (0.290)**	0.759 (0.222)***	0.875 (0.229)***	0.783 (0.127)***	0.538 (0.111)***	0.409 (0.149)***
LCC 2	0.627 (0.248)**	0.119 (0.188)	0.205 (0.220)	0.151 (0.112)	-0.026 (0.097)	-0.038 (0.093)
LCC 3	0.072 (0.193)	-0.244 (0.181)	-0.131 (0.217)	-0.146 (0.104)	-0.318 (0.092)***	-0.243 (0.088)***
LCC 4	-	-0.605 (0.208)***	-0.397 (0.244)	-0.297 (0.134)**	-0.351 (0.148)**	-0.319 (0.110)***
Prime farmland	0.441 (0.251)*	0.191 (0.076)**	0.041 (0.051)	0.052 (0.047)	0.073 (0.043)*	0.203 (0.039)***
Slope	0.063 (0.125)	0.009 (0.022)	-0.020 (0.022)	-0.006 (0.020)	-0.021 (0.020)	0.022 (0.014)
Flood potential	-	-0.046 (0.044)	-0.021 (0.065)	-0.031 (0.070)	-0.132 (0.047)***	-0.124 (0.047)***
Wind erosion	0.031 (0.011)***	0.032 (0.006)***	0.022 (0.006)***	0.017 (0.004)***	0.019 (0.004)***	0.013 (0.003)***
Water erosion	0.111 (0.165)	0.010 (0.007)	0.023 (0.015)	0.005 (0.016)	0.013 (0.012)	0.002 (0.007)
Dist. KS border	-0.062 (0.031)**	0.006 (0.010)	-0.002 (0.005)	-0.006 (0.003)*	-0.002 (0.002)	<0.001 (0.002)
Shr. farmland irrig.	-0.602 (2.272)	0.119 (0.990)	0.468 (0.791)	-1.020 (0.753)	1.293 (0.641)**	1.361 (0.530)**
Shr. farmland rented	-1.015 (1.229)	0.257 (0.635)	1.079 (0.508)**	0.551 (0.398)	1.073 (0.392)***	0.580 (0.330)*
Shr. farmland corp.	-0.222 (1.377)	0.733 (0.556)	0.928 (0.419)**	0.393 (0.370)	0.512 (0.373)	0.725 (0.317)**
Farm real est. value	0.001 (0.001)	<0.001 (<0.001)	<0.001 (<0.001)	0.001 (<0.001)*	<0.001 (<0.001)	<0.001 (<0.001)
No. observations	896	2,583	4,165	5,173	7,070	10,304
No. plots (w/ repeats)	128	369	595	739	1,010	1,472
No. plots (no repeats)	102	277	421	510	670	931

Notes: The estimates displayed above are for the control variables in the models used to produce the UVA effects in Tables 4 and E1. The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E11. Irrigation Model, Oklahoma Border Segment, UVA Effect Estimates by Year and Bandwidth, Unmatched Sample

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.010 (0.011)	-0.009 (0.007)	-0.017 (0.007)**	-0.014 (0.006)**	-0.012 (0.005)**	-0.008 (0.005)*
1992	-0.043 (0.027)	-0.056 (0.020)***	-0.041 (0.017)**	-0.027 (0.013)**	-0.021 (0.012)*	-0.015 (0.009)
1997	-0.109 (0.043)**	-0.050 (0.023)**	-0.032 (0.019)*	-0.019 (0.015)	-0.017 (0.013)	0.009 (0.017)
2002	-0.063 (0.052)	0.052 (0.037)	0.027 (0.027)	0.027 (0.023)	0.022 (0.021)	0.054 (0.020)***
2007	-0.051 (0.052)	0.042 (0.033)	0.035 (0.025)	0.034 (0.023)	0.033 (0.020)	0.053 (0.018)***
2012	-0.031 (0.051)	0.060 (0.033)*	0.047 (0.025)*	0.043 (0.023)*	0.041 (0.020)**	0.066 (0.020)***
No. observations	3,262	6,503	9,121	11,473	14,511	19,278
No. plots (w/ repeats)	466	929	1,303	1,639	2,073	2,754
No. plots (no repeats)	219	461	671	860	1,122	1,513

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.

Table E12. Irrigation Model, Oklahoma Border Segment, UVA Effect Estimates by Year and Bandwidth, Alternative Specification with Post-UVA Plot Attribute Interaction Terms

Bandwidth (mi.)	5	10	15	20	25	None
1987	>-0.001 (0.001)	-0.012 (0.011)	-0.012 (0.008)	-0.019 (0.010)*	-0.018 (0.008)**	-0.009 (0.005)*
1992	-0.025 (0.054)	-0.087 (0.027)***	-0.032 (0.020)	-0.041 (0.022)*	-0.017 (0.019)	-0.020 (0.015)
1997	-0.102 (0.065)	-0.071 (0.033)**	-0.032 (0.024)	-0.043 (0.025)*	-0.016 (0.021)	0.017 (0.024)
2002	-0.103 (0.081)	-0.037 (0.041)	<0.001 (0.029)	-0.019 (0.031)	-0.004 (0.029)	0.056 (0.027)**
2007	-0.088 (0.082)	-0.021 (0.041)	0.012 (0.030)	-0.001 (0.032)	0.009 (0.029)	0.050 (0.023)**
2012	-0.045 (0.082)	0.015 (0.038)	0.035 (0.028)	0.016 (0.030)	0.021 (0.029)	0.068 (0.026)***
No. observations	896	2,583	4,165	5,173	7,070	10,304
No. plots (w/ repeats)	128	369	595	739	1,010	1,472
No. plots (no repeats)	102	277	421	510	670	931

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes, and interaction variables between the controls and a post-1987 dummy variable.

Table E13. Irrigation Model, Oklahoma Border Segment, UVA Effect Estimates by Year and Bandwidth, Matching with Replacement

Bandwidth (mi.)	5	10	15	20	25	None
1987	-0.001 (0.001)	-0.015 (0.015)	-0.004 (0.003)	-0.014 (0.011)	-0.007 (0.004)	-0.006 (0.005)
1992	-0.005 (0.037)	-0.009 (0.021)	-0.019 (0.015)	-0.019 (0.015)	-0.015 (0.011)	-0.028 (0.022)
1997	-0.062 (0.050)	0.015 (0.025)	-0.023 (0.025)	-0.014 (0.021)	0.001 (0.013)	0.014 (0.026)
2002	-0.037 (0.053)	0.075 (0.043)*	-0.003 (0.041)	-0.109 (0.077)	-0.010 (0.048)	0.042 (0.036)
2007	-0.026 (0.055)	0.084 (0.043)*	0.003 (0.041)	-0.105 (0.077)	-0.013 (0.047)	0.027 (0.033)
2012	-0.026 (0.056)	0.111 (0.038)***	0.039 (0.030)	-0.059 (0.078)	0.006 (0.046)	0.039 (0.032)
No. observations	861	2,716	4,494	6,321	9,821	11,914
No. plots (w/ repeats)	123	388	642	903	1,403	1,702
No. plots (no repeats)	123	317	504	666	940	1,121

Notes: The dependent variable in the above models is binary and takes a value of 1 if a plot is irrigated. Asterisks denote significance at the 10% (\*), 5% (\*\*), and 1% (\*\*\*) levels. Standard errors are clustered by National Resources Inventory (NRI) plot. The baseline year is 1982 in all models. Estimates are weighted using NRI expansion factors divided for the number of times each plot is stacked due to its county having multiple contiguous cross-border counties. All models include a set of contiguous-county border-pair dummy variables, time fixed effects, border-pair time fixed effects, a baseline Kansas dummy variable, a constant term, and controls representing plot characteristics and county attributes.