Title

Land Market Valuation of Groundwater

JEL Codes: Q15, Q25, Q51

Keywords: Agriculture, Groundwater, Hedonic, High Plains Aquifer, Irrigation, Valuation

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Abstract

We estimate irrigation premiums and implicit marginal valuations of water in-storage using parcel-level transaction data for land sales in the Kansas portion of the High Plains Aquifer. We find that agricultural land values are 53% higher for irrigated parcels than non-irrigated parcels on average and that the irrigation premium has increased at an average rate of 1.0 percentage points per year over the sample period (1988-2015). Spatial heterogeneity in irrigation premiums is explained by differences in saturated thickness of the aquifer. Water in-storage is capitalized into land prices at average marginal values ranging from $3.42/acre-ft to $15.86/acre-ft.

Introduction

Water resources are fundamental to agricultural production in arid parts of the world such as the California Central Valley, the Great Plains region of the United States, and many parts of Asia. Increasingly, irrigation water for agriculture is sourced from aquifers (Wada, et al., 2010). In the United States, over 56 million acres of agricultural land is irrigated and approximately 60% of this total is irrigated from groundwater (Siebert, et al., 2010). Growing dependence of agricultural production on groundwater is causing rapid depletion of large aquifers, however. In the United States, depletion of the Kansas portion of the High Plains Aquifer is particularly problematic.

It is difficult to directly observe the marginal value of groundwater used in agriculture due to a general lack of competitive water markets. One approach to assess the value of groundwater irrigation is to use calibrated programming models (Howitt, 1995) that identify optimal inputs given irrigation water limitations (Koundouri, 2004 reviews the literature). The value of irrigation is obtained as a shadow value of the optimization program (e.g., Ziolkowska, 2015, Fenichel, et al., 2016). An alternative approach to estimating the value of groundwater irrigation is to use revealed preference methods such as the hedonic price model, which obtains an implicit valuation of irrigation availability as a differentiated attribute of farmland (Rosen, 1974).

This paper takes the hedonic price model approach to determine the implicit values of irrigation and groundwater in-storage for irrigated parcels. In particular, we combine a unique set of land sale transaction data with spatially explicit hydrological characteristics for the Kansas portion of the High Plains Aquifer to analyze the effects of groundwater availability on land values. Spatial and temporal variation in depth to water across the aquifer are exploited to analyze impacts of changes in saturated thickness (i.e. groundwater stocks) on land values. Kansas is a top 10 national producer of wheat, grain sorghum, and grain corn and the High Plains Aquifer is the main source of irrigation used in agricultural production. Secure availability of irrigation water, therefore, has direct policy relevance and information on marginal values of irrigation water is consequential to public policy makers who are challenged with managing changing groundwater stocks.

The hedonic price model approach has been used to evaluate a wide range of environmental policies, from the Clean Air Act (Chay, et al., 2005) to Superfund (Greenstone and Gallagher, 2008). Hedonic modeling has also been undertaken to evaluate the effects of water quality on residential real estate (Leggett and Bockstael, 2000, Walsh, et al., 2017), the effects of climate on agriculture (Mendelsohn, et al., 1994, Schlenker, et al., 2005, Ashenfelter and Storchmann, 2010), and the economic impact of changes in groundwater supplies on agricultural land values (Faux and Perry, 1999, Mendelsohn and Dinar, 2003, Schlenker, et al., 2007, Hornbeck and Keskin, 2014). With respect to hedonic analyses of agricultural groundwater, the literature has produced mixed conclusions. For instance, Torell et al. (1990) and Hornbeck and Keskin (2014) find a statistically significant relationship between groundwater and farmland values while neither Schlenker et al. (2007) nor Mendelsohn and Dinar (2003) find statistical significance. Recently, there has been a surge of methodological studies on how spatial measurement of localized amenities affects hedonic estimates (Abbott and Klaiber, 2011, Gamper-Rabindran and Timmins, 2013). A related literature has demonstrated the use of quasi-experimental techniques to control for time-variant and time-invariant omitted variables (Kuminoff, et al., 2010, Klaiber and Smith, 2013).

This paper provides two innovations to the existing literature. First, rather than relying on land values from county-level census data (e.g. Hornbeck and Keskin, 2014), we are able to exploit a unique set of parcel-level transaction data across the state of Kansas from the Property Valuation

Division (PVD) of the Kansas Department of Revenue (Fig. 1). Second, we are able to exploit a rich set of highly spatially resolved data on soil, weather, and hydrologic characteristics that plausibly affect agricultural land values and evolution of the aquifer (e.g., Figs. 2, A1, and A2). Highly resolved spatial-temporal variation in saturated thickness allow the identification of marginal capitalized values of water in-storage, whereas previous studies have largely focused on average values of water in-storage. The policy relevance of average valuations of water in-storage is limited to extreme scenarios such as running out of water. Conversely, marginal valuations of water in-storage are more appropriate for evaluating changes in groundwater stocks across space and time. Thus, this paper explores an important aspect of groundwater valuation – how sensitive irrigated farmland values are to changes in stocks of groundwater. Research in this area can provide important information to managers.

We find that agricultural land values are about 53% higher for irrigated parcels than non-irrigated parcels on average. Moreover, the land value premium for irrigated parcels increased at an average rate of about 1.0 percentage points per year over the sample period (1988-2015). There is also substantial spatial heterogeneity in irrigation premiums. Our results indicate that irrigation premiums are highest for regions having the greatest stocks of groundwater. We also estimate the capitalized value of saturated thickness (a measure of the stock of groundwater available for future irrigation) in farmland sales. The average marginal value that water in-storage contributes to the price per acre of farmland is estimated to be \$3.42/ft (i.e. \$3.42/acre-ft).[1] However, using a

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[1] Land valuations are standardized as dollar per acre. Thus, marginal valuations of the change (in ft) in saturated thickness can be interpreted in dollars per acre-ft. Note that the measurement is not a literal acre-ft of water for irrigation because of later flow and recharge and potential differences in specific yield.

subsample of repeat sales in a parcel fixed effects framework, we estimate that the marginal value of water in-storage may be as high as $15.85/acre-ft.

Study area and background

Our study area is the state of Kansas, where production agriculture relies heavily on groundwater irrigation from the High Plains Aquifer. Kansas ranks in the top 10 nationally in wheat, grain sorghum, and grain corn production. Irrigation water withdrawals from the Kansas High Plains Aquifer are about 3.5 million acre-feet annually, which are used to irrigate about 3 million acres. Recharge of the aquifer is low relative to the annual withdrawals and water tables have dropped since predevelopment. Secure water availability for agriculture is a significant concern going forward.

Rights to groundwater in Kansas are both appurtenant to and severable from the land (K.S.A. 82a-701(g)). This means that a water right holder may sell the land with the appurtenant water right. Land transactions with an appurtenant water right are the most straightforward and do not require approval of the state chief engineer. In principle, a holder may also sell the land but retain the water right (i.e. a severable right). However, land transactions with a severable water right present onerous transactions costs if the water right is to be exercised in a different location. Water rights in Kansas are limited in several important ways. First, a water right is limited in maximum annual quantity (i.e. acre-feet) and rates of withdrawal (i.e. gallons per minute) (K.S.A. 82a-701(f)). Second, the water can only be put to beneficial use within authorized locations (K.S.A. 82a-712). Third, the water can only be withdrawn from authorized points of diversion (K.S.A. 82a-701(f)). Any proposed change must demonstrate that it will not materially injure a more senior right. Additionally, a holder seeking to make a change to the water right must demonstrate that the change will pertain to the “same local source of supply” authorized in the original right (K.S.A. 1987 Supp. 82a-708b (a)(3)). The state chief engineer has a stringent policy pertaining to “local” as one-quarter mile or less within the same aquifer.

There is a rich literature investigating farmland amenity values through stated and revealed preference (Bergstrom and Ready, 2009 reviews the literature). Previous work has demonstrated that the availability of groundwater for agricultural production has affected land values in the High Plains Aquifer region (Lee and Bagley, 1972, Torell, et al., 1990, Brozović and Islam, 2010, Hornbeck and Keskin, 2014, Jenkins, et al., 2017, Ifft, et al., 2018). Related research has demonstrated the significance of irrigation to agricultural land values in broader contexts (Xu, et al., 1993, Darwin, 1999, Faux and Perry, 1999, Mendelsohn and Dinar, 2003, Buck, et al., 2014). Other research has estimated value added by irrigation to agricultural production using yield functions (Peterson and Ding, 2005, García Suárez, et al., 2018).

One of the earliest studies to document implicit irrigation premiums in Kansas is Lee and Bagley (1972), who estimate a value of approximately \$600/acre (after converting to present dollars) using farmland sales price data for southwestern Kansas. Torell et al. (1990) use data for the five states overlying the Ogallala Aquifer and find irrigation premiums ranging from \$500 to \$1,300 per acre and that the premiums declined over the study period (1979-1986). More recently, Brozović and Islam (2010) use sales data from a single county in Nebraska and find irrigation premiums of approximately \$720 per acre, but find no effect of depth to water on land values. Hornbeck and Keskin (2014) compare land values of counties inside the High Plains Aquifer boundary to those just outside the boundary controlling for climate and soil characteristics. Hornbeck and Keskin (2014) find that the land value premium from irrigation peaked in the 1960s and declined until 2002 (the most recent year in their analysis). Jenkins et al (2017) find that distinctions in water marketing rights across the states overlying the High Plains Aquifer generate differences to the implicit value of groundwater for agriculture. Ifft et al. (2018) use plot-level data from Nebraska and find no impact of irrigation restrictions on land values, on average.

Empirical strategy

We model land values in a hedonic pricing framework. The premise of the hedonic model is that the i^{th} parcel is a good composed of a bundle of observable attributes $\mathcal{Z}_i$ (Rosen, 1974). Of particular significance is that in hedonic analysis the price of agricultural land equals the net present value of economic rents from agriculture. Additionally, the price of the stock of groundwater below a parcel as a differentiated attribute is the shadow value in terms of net present value of the resource in situ (Dasgupta and Heal, 1979, Koundouri and Xepapadeas, 2004).[2] Let the real price per acre for $\mathcal{Z}_i$ as a function of its attributes be $P(\mathcal{Z}_i)$. Farmland price functions are obtained by regressing observed market price for a parcel, P_i, on its attributes, $\mathcal{Z}_i$. The $\mathcal{Z}_i$ vector in this analysis is composed of various subvectors over the following characteristics: irrigation status IRR, aquifer characteristics and characteristics of the water right affecting irrigated production z^W, location-specific soils and long-run weather characteristics affecting irrigated and non-irrigated production z^{DL}, and other characteristics (e.g. demographics) affecting irrigated and non-irrigated parcels alike z^v. Irrigation status (IRR) measures the land value premium provided by the presence of one or more water rights for agricultural irrigation. In total, the observed price in the market for $\mathcal{Z}_i$ can be represented by:

$$P(\mathcal{Z}_i) = P(IRR, z^W, z^{DL}, z^v) \tag{1}$$

Determining the Value of Groundwater Availability

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[2] Formally, the shadow value can be defined as the costate variable associated with the equation of motion in an optimal control framework or as the derivative of the problem's value function with respect to the stock in a dynamic optimization framework.

To determine the value of groundwater availability, we specify that the value of irrigated land is equal to the discounted present value of the future stream of earnings from the land and groundwater. Adding to this the value of the other associated hedonic characteristics in (1), we obtain the following form for parcel i evaluated in the base year:

$$P_i^{IRR} = \int_{t=0}^{\infty} e^{-\rho t} \left(R_i^{IRR}(t) + R_i^{DL}(t) \right) dt + \nu_i \tag{2}$$

where P_i^{IRR} is the observed land price per acre for irrigated parcel i in the base period and ρ is the rate of discount. We express P_i^{IRR} as three parts: (i) the present value of rents in excess of dryland rents from the groundwater resource providing irrigation (R_i^{IRR}), (ii) the present value of rents from dryland agricultural production (R_i^{DL}), and (iii) the value of all other income and price influences (ν_i).

The price for non-irrigated parcels is expressed as:

$$P_i^{DL} = \int_{t=0}^{\infty} e^{-\rho t} R_i^{DL}(t) dt + \nu_i \tag{3}$$

where P_i^{DL} is the observed land price per acre for a dryland parcel i in the base period.

A key component of R_i^{IRR} is the saturated thickness of the aquifer (denoted as ST_{it} below). We allow for declining marginal value of the stock of groundwater by specifying a quadratic form for saturated thickness. Additional data composing R_i^{IRR} include location-specific hydraulic conductivity (HC_{it}) and authorized inches of irrigation per acre according to parcel $i's$ water right (denoted by w_{it}). The data composing R_i^{DL} include various soils and climate characteristics (denoted by the vector z_{it}^{DL} for dryland). Additionally, we define IRR_{it} as a dummy variable taking on one for parcel i if it is irrigated at time t. The vector z_i^{v} includes various measurements for distance to major population centers. Hedonic theory does not indicate a strict functional form that ought to be used in the hedonic pricing model. The semi-log is a commonly used functional form because of the ease of interpreting coefficients as proportional change and also to handle binary variables, though there are others which we describe and test for completeness below. Taken together, the estimating equation for the real price per acre for parcel i in year t is:

$$\ln \frac{Price}{Acre}_{i,t} = \beta_1 IRR_{it} + IRR_{it}(\beta_2 ST_{it} + \beta_{22} ST_{it}^2 + \beta_3 HC_{it} + \beta_4 w_{it}) + \beta_5 ST_{it} + \beta_{55} ST_{it}^2 + \beta_6 HC_{it} + \xi' z_{it}^{DL} + \Omega' z_i^v + \eta_l + \tau_{d,t,q} + \epsilon_{it} \quad (4)$$

Thus, aquifer characteristics (ST_{it}, HC_{it}) can differentially affect the price for parcel i if it is an irrigated parcel. Additionally, water right characteristics (w_{it}) only affect the price for parcel i if it is an irrigated parcel.[3] Groundwater management district (GMD) by year by quarter dummies $\tau_{d,t,q}$ are included in all specifications to control for spatial-temporal factors influencing land sales prices (e.g. commodity price fluctuations or irrigation rules that could affect districts differentially).[4] Spatial dummies, η_l, are used to control for time-invariant unobserved heterogeneity in land prices. Our scale of spatial dummies ranges from no controls to controlling at the township level (i.e. 603 total units roughly 6 miles x 6 miles).

In order to make predictions of the model in levels more attractive and to avoid potential bias from OLS estimates of the log-linearized model (e.g. Silva and Tenreyro, 2006), we estimate (4) using a generalized linear model (GLM) with a log link function.[5] That is, define $\mu = E\left(\frac{price}{acre}\right)$ and $\zeta = g(\mu) = \ln \mu$. Then, $g(\mu)$ maps $E\left(\frac{price}{acre}\right)$ to $\zeta = \beta_1 IRR_{it} + IRR_{it}(\beta_2 ST_{it} + \beta_{22} ST_{it}^2 +$

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[3] The goal of the paper is to value groundwater for agricultural irrigation. We do not expect groundwater for domestic purposes to affect our estimates for two reasons. First, there is very little urban development pressure over the High Plains Aquifer. Second, domestic wells can be operated at well yields substantially lower than minimum recommended irrigation well yields.

[4] GMDs are local government bodies which provide water use planning and management, subject to approval by the Kansas Chief Engineer. In total, there are five GMDs in Kansas that were formed between 1973 and 1976.

[5] Because in this case the distribution family is still Gaussian, the GLM estimator is closely related to the OLS estimator. The key difference in the GLM is that the mean of the dependent variable is transformed by the link function rather than transforming all observations of the dependent variable.

$\beta_3 HC_{it} + \beta_4 w_{it}) + \beta_5 ST_{it} + \beta_{55} ST_{it}^2 + \beta_6 HC_{it} + \xi' z_{it}^{DL} + \Omega' z_i^v$. We complete the model by clustering standard errors at the county level (the highest level of aggregation) to account for potential heteroscedasticity and spatially correlated errors.

A common concern in hedonic models is that omitted variables may be correlated with the key variables of interest. For example, perhaps land better suited for crop production was developed for irrigation such that the coefficient on irrigation captures other characteristics of the land. In Kansas, irrigation development occurred rapidly from 1945 to about 1978. But in the 1980's irrigated acreage stabilized because the Kansas Department of Agriculture authorized few new water right permits due to concerns about the effect of over-appropriation on existing water right holders (i.e. safe yield calculations) (Sampson and Perry, 2019). Therefore, there are non-irrigated parcels today that could be profitably developed for irrigation, but cannot be developed because they cannot obtain a water right permit. When identifying irrigation premiums, our estimation strategy exploits non-irrigated parcels as counterfactual parcels because they represent similar parcels as an irrigated parcel conditional on all the controls. Hornbeck and Keskin (2014) rely on counties outside the aquifer boundary as the counterfactual, but we can exploit parcels within the same county (or finer resolution) as the counterfactual because we have parcel-level data.

Other threats to identification are that differential rates of depletion over time and space might affect land values. With respect to possible differences in the rate of depletion across space, this is unlikely to be a concern in our context because average rates of depletion that differ across space will be primarily controlled for by the inclusion of spatial dummy variables (e.g., variation in the rate of depletion due to cross sectional differences in the rate of recharge). Moreover, we also include GMD by year by quarter dummies in each of the main specifications to capture aggregate changes in the rate of depletion for each portion of the aquifer (Figs. A1, A2). Thus, change in the rate of depletion would need to vary within a GMD within a year-quarter and significantly affect land values in order to bias our estimates.[6] While we include a rich set of spatial controls, we cannot be certain that all cross sectional heterogeneity between parcels is controlled for. We therefore test the robustness of the main results by estimating hedonic models using parcel-level controls for a subset of the data having repeat sales. These are the finest possible level of fixed effects and therefore ameliorate any concern about time-invariant unobservables.[7]

Consideration of Functional Form

Hedonic price theory does not provide guidelines for functional form in empirical applications. The Box-Cox transformation is a commonly used method to test several different popular specifications. Cropper et al. (1988) use simulation to show that with no omitted variables, linear and quadratic Box-Cox transformed variables provide the best goodness-of-fit in estimating hedonic price functions. However, when mis-specification is a possibility, then simple linear, semi-log, and Box-Cox linear outperform quadratic and Box-Cox quadratic functions (Cropper, et al., 1988). Based on the evidence in Cropper et al. (1988) and concerns for omitted variables, many studies have relied on simple functional forms (Kuminoff, et al., 2010 reviews the literature). This includes the study by Torell et al. (1990), who estimate the value of water in-storage most comparable to our own estimates. In order to build off of existing studies, we consider the semi-

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[6] We did explore models which explicitly control for average annual historical depletion. Our estimates of irrigation premium and the average value of water in storage are effectively unchanged. Additionally, the coefficient estimates on annual historical depletion is negative (suggesting prior depletion is correlated with larger land values) but not statistically significant.

[7] One concern with using such a rich set of controls is leaving little residual variation in saturated thickness (e.g., Fisher, et al., 2012). To investigate this, we regress saturated thickness on all covariates and controls and then capture the residuals. We find the average of the absolute value of the residuals is 18, which is about 11% as large as the average saturated thickness for irrigated parcels. The residuals are also well mixed across space (Fig. A3).

log specification as the relevant baseline functional form. To test the sensitivity of our results to functional form, we also estimate Poisson and Box-Cox models in later sections.

Data

The data used for our estimation are drawn from multiple sources at the finest resolution possible. Table 1 presents summary statistics of the variables used in model estimation. Next, we discuss each source of data.

Land Transactions

A unique aspect of our research is parcel-level sales data for every agricultural land transaction in Kansas that is at least 40 acres in size from 1988 to 2015 obtained from the Property Valuation Division (PVD) of the Kansas Department of Revenue (Fig. 1). We restrict our analysis to parcels overlaying the High Plains Aquifer that are at least 75% cropland by area to ensure appropriate comparisons of agricultural land between irrigated and non-irrigated parcels.[8] We also restrict analysis to arms-length transactions to ensure accurate reflections of fair market values. In total we have data on 17,312 transactions. Our PVD sales data include information on total amount of sale, estimates of dollar amount improvements to land, and acres of the parcel that are dryland or irrigated.[9] We define an irrigated parcel as any parcel that is more than 70% irrigated by area and we exclude parcels from our sample that had some irrigation but were less than 70% irrigated.[10] It is rare for a parcel to be 100% irrigated in Kansas due to center pivot irrigation that leaves corners non-irrigated. We exclude the value of improvements from the price because this

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[8] There is very limited surface water availability in the High Plains Aquifer region. We therefore expect little surface water irrigation.

[9] Additional details of the PVD transaction data are described in Tsoodle et al. (2006).

[10] 844 observations are excluded for having some irrigation but less than 70% irrigated by area.

usually reflects the value of homes and buildings. All prices are converted to 2015 dollars using the consumer price index.

Soils

Soils characteristics likely to affect rents to dryland and irrigated parcels are obtained from the SSURGO soil survey on the website of the USDA Natural Resource Conservation Service (NRCS). The PVD data contain information on the acres of the parcel represented by each soil type. We link these soil types to the SSURGO data that provide information on the characteristics of each soil type and aggregate the characteristics to the parcel level. These characteristics include detailed information on soil composition and water storability. Our regression specifications include the following soil characteristics as controls: proportion of parcel with pH less than 6 (acidic soils), proportion of parcel with pH greater than 7.5 (basic soils), plant available water storage, and soil organic carbon. These soil characteristics were chosen to represent agricultural productivity and water storability.

Climate

Daily gridded weather data are obtained from PRISM and are linked to sections of the Public Land Survey System (PLSS), which are then merged to the parcels. We construct four long run climate variables (1981-2012 average) for each section: average precipitation during the growing season, the average number of annual degree days between 10 and 32 degrees Celsius, the average number of annual degree days greater than 32 degrees Celsius (heat levels that are detrimental to crop growth (Schlenker, et al., 2006)), and average reference evapotranspiration during the growing season.

Hydrology

Spatially explicit hydrology characteristics for the High Plains Aquifer are obtained from the Kansas Geological Survey (KGS). These variables include hydraulic conductivity and saturated thickness at five-year intervals. Saturated thickness is spatially interpolated from a set of 1,320 groundwater monitoring wells maintained by the KGS (Fig. 2). Each five-year interval of saturated thickness is the center of a three-year average measured during the winter after water levels have recovered from pumping during irrigation season.[11] This measure of saturated thickness is expected to accurately reflect saturated thickness at the parcel at the time of the land transaction and is consistent with USGS and Kansas Geological Survey methods for mapping saturated thickness across the aquifer. Saturated thickness has generally declined over the period of analysis (Figs. A1, A2). However, there are also some temporary periods of recovery in saturated thickness.

As noted, our scale of spatial dummies ranges from no controls to controlling at the township level. Thus, with spatial controls at the township level and GMD by year by quarter dummies, the identifying variation in saturated thickness will come from cross sectional variation in saturated thickness within a township and time series variation in saturated thickness within the township that is not common across all townships within a GMD. We do not obtain well capacity data. However, well capacity is a function of saturated thickness and hydraulic conductivity, which we include in the regressions (Hecox, et al., 2002). Greater hydraulic conductivity should decrease pumping costs, as water moves more freely across porous spaces of the aquifer. Saturated thickness is our measure of the stock of available groundwater beneath the parcel for present and future irrigation. We expect positive coefficients on hydraulic conductivity and saturated thickness.

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[11] Winter measurements (also known as static water level) avoid any potential noise associated with irrigation pumping activity during growing seasons. Additionally, the three-year average will smooth annual variation such as weather or recharge.

Water Rights

Information about the authorized annual quantity of groundwater extraction are obtained from the Water Information Management and Analysis System maintained by the Kansas Division of Water Resources and are spatially matched to the coordinates of the parcel. Our regression specifications include information on the quantity of water authorized for irrigation divided by the total number of acres authorized for irrigation (i.e. authorized quantity per acre). As mentioned earlier, it is possible for a water right to be severable from the land. However, water rights transactions that are separate from land title transactions are accompanied by substantial permitting burdens. For this reason, we make the assumption that any water rights are appurtenant to the land transaction. If the PVD data indicate that a portion of the parcel is irrigated, then the water right should be transferred in the transaction.

There are two regions that experienced a significant change in groundwater use regulations affecting water rights during the period of analysis. The first is the Walnut Creek Intensive Groundwater Use Control Area (IGUCA), which is located on the western edge of GMD 5. Starting in 1992, the IGUCA stopped authorization of new water permits and imposed restriction on existing agricultural water rights depending on the seniority of the right (Golden and Leatherman, 2017). The second is the Sheridan County Local Enhanced Management Area (LEMA) in GMD 4, which imposed a 20% reduction in aggregate extraction across users in 2012 (Drysdale and Hendricks, 2018). In the data, we only observe 25 irrigated parcel transactions since 1992 in the IGUCA and zero irrigated transactions since 2012 in the LEMA. Because we also specify GMD by year by quarter controls, we do not feel that changes in management regimes are a concern for model estimates in this context.

Urban Influence

We control for urban influence by using data on the commute time to a city with population 10,000 or more and commute time to a city with population 40,000 or more. Commute times are calculated from the parcel using Google Maps. We censor the commute times at 0.5 hours for cities of 10,000 or more and 1.0 hours for cities of 40,000 or more. That is, we assume that being closer to a city has an impact on land values only if a parcel is within 30 minutes of a small city or 60 minutes of a large city.

Results and discussion

We center all continuous independent variables on their mean so that the coefficient on the irrigated parcel dummy is interpreted as the effect of irrigation on land values having average characteristics. The main results of the analysis are summarized in Table 2, which presents results using GLM with a log link. The dependent variable in all specifications is the log of the real price of land and the focal independent variables are a dummy variable for whether the parcel is irrigated and saturated thickness of the aquifer. We allow for declining marginal value of water in-storage by specifying saturated thickness as a quadratic function. All specifications control for unobserved spatial-temporal variation, such as commodity price shocks, by including GMD by year by quarter dummies (see Fig. 1 for GMD locations). In column 1, we present estimates when no spatial controls for time-invariant heterogeneity are included. In column 2, we control for unobserved spatial heterogeneity by including dummies for the 36 counties in our study area. In column 3, we present point estimates when county subdivision-level dummies are included. County subdivisions are defined by the US Census Bureau and are delineated for the purpose of reporting census data. There are 240 county subdivisions in our study area (e.g., Fig. 2). Column 4 uses township (6 miles x 6 miles) dummies to control for time invariant heterogeneity at the finest scale (603 total).

Looking across specifications, our results provide clear evidence of a substantial irrigation premium in land sales transactions. Regardless of whether we include county, subdivision, or township controls, the point estimate on irrigated parcels is positive and economically and statistically significant at 0.01. The coefficient on irrigation is presented as a semi-elasticity. Thus, parcels that are irrigated fetch about a 53% premium over dryland parcels, on average. The value of land represents one of the most important capital assets determining the wealth portfolio for agricultural producers (United States Department of Agriculture, 2019). Here we demonstrate that the ability to irrigate contributes substantially to producer wealth by increasing the value of farmland. In terms of policy, a main inference is that mandatory irrigation curtailments or retirement programs are likely to have major implications for producer wellbeing and even for solvency.

The other focal independent variable is saturated thickness, which is a measure of water in-storage for parcels having irrigation rights. The coefficients on saturated thickness and its square (reported in 100s of feet) indicate there are diminishing marginal valuations of water in-storage. This pattern is consistent across specifications. We observe the effect of saturated thickness getting stronger and more statistically significant as more spatial controls are added, suggesting that unobserved spatial heterogeneity is correlated with land values and saturated thickness. This lends support for our use of spatial controls. In addition to coefficient estimates on saturated thickness, we report average marginal effects for irrigated and non-irrigated parcels at the bottom of Table 2. Our estimates when controlling for township dummies indicate that the average marginal per-acre capitalized value of water in-storage is about \$3.42/ft. As expected, saturated thickness has no statistically significant effect on non-irrigated land values—providing support for our specification in that saturated thickness is not correlated with unobserved land productivity.

For ease of interpretation, we also convert the semi-elasticities in Table 2 to model predictions for valuations at different levels of saturated thickness. These are presented in Figure 3. Using the specification in column 4, a parcel having average saturated thickness (about 170 feet) is valued at $2,886/acre. By comparison, an otherwise equivalent irrigated parcel having saturated thickness of 75 feet is estimated to have a 14% lower value ($2,486/acre vs $2,886/acre). A parcel with saturated thickness of 275 feet is estimated to have a value that is 9% greater than an equivalent parcel having average saturated thickness ($3,137/acres vs. $2,886/acre).

As groundwater tables fall, changes in producer wellbeing and value of the aquifer are most appropriately measured using marginal valuations of groundwater stocks. With respect to groundwater policy, our estimates are important for documenting how farmland values (and therefore producer wealth) change with changing groundwater stocks. Additionally, our estimates of the marginal value of water in-storage provide a benchmark against which investments made toward groundwater conservation can be compared.

Our results highlight the role of other soil and climate characteristics in determining land prices. As expected, greater soil organic carbon increases parcel prices. The effect of soil organic carbon does not appear to be different for irrigated and non-irrigated land. Precipitation generally does not affect farmland prices in meaningful ways net of the other controls. For our preferred specification in column 4, increased degree days between 10 and 32 Celsius (i.e. favorable growing conditions) lead to increased parcel prices while increased degree days over 32 Celsius (i.e. unfavorable conditions) lead to decreased parcel prices. Lastly, there is evidence that increased hydraulic conductivity increases land values for irrigated parcels.

Land Values and Irrigation Premiums Over Time

Prior research has questioned whether implicit prices can be treated as time invariant when evaluating over long time periods (Kuminoff, et al., 2010). We explore whether the implicit irrigation premiums should be regarded as time invariant due to the relatively long 28-year period of analysis (1988-2015). For instance, our land transaction data covers the food commodity price boom of the late 2000s. Between 2002 and 2008, price indexes for basic crops (wheat, rice, corn, soybeans) rose over 220%, compared with a 130% increase for overall food commodities (Trostle, 2011). We also evaluate how the average marginal value of water in-storage has changed over time.

First, to explore statewide differential rates of growth between the real prices of non-irrigated and irrigated parcels, we interact a linear time trend with the irrigation dummy. Additionally, we interact the saturated thickness variables with a linear time trend to explore dynamic values of water in-storage. Results of interacting a statewide trend with the irrigation dummy are presented in column 1 of Table 3 (full results reported in Table A1). We find that on average the growth rate of the real price per acre for irrigated parcels has been 0.98% larger than for non-irrigated parcels and this difference is significant at 0.10. We further find that the average marginal per-acre capitalized value of water in-storage has been growing over time, from about \$2.00/ft in 1988 to about \$8.00/ft in 2015 (Fig. A4).

We also explore spatial-temporally varying differences in irrigation premium growth rates. In column 2 of Table 3, we estimate a model where the irrigation dummy is interacted with linear time trends that are specific to the five GMDs in our study area (Fig. 1) (full results reported in Table A1). We control for statewide year by quarter dummies instead of GMD by year by quarter dummies to avoid multicollinearity of the GMD-specific trends. We find that in GMD No. 3 (southwest Kansas) and GMD No. 5 (southcentral Kansas), the annual real price growth for irrigated parcels outpaced non-irrigated parcels by about 1%, though the difference is only statistically significant for GMD No. 5. Saturated thickness of the Kansas High Plains Aquifer is greatest in the southern part of the state (Fig. 2). Thus, our findings suggest that irrigation premiums have grown in the areas having the largest groundwater stocks.

Our temporal analysis has policy and methodological implications. With respect to policy, our results provide information on how agricultural producer wealth from groundwater has changed through time. Real irrigation premiums and marginal values of water in-storage have grown over time, while saturated thickness of the aquifer has generally experienced long run declines (i.e., became more scarce). Matching temporal changes in marginal valuations with changing groundwater stocks is important when calculating the total value of the aquifer through time (Fenichel, et al., 2016). Additionally, our results underscore previous studies citing the need to adjust hedonic specifications to account for potential changes in the hedonic price function of irrigation water use through time (e.g., Ifft, et al., 2018).

Spatial Heterogeneity in Irrigation Premiums

We investigate spatial heterogeneity in irrigation premiums by predicting dryland and irrigated price per acre for each parcel in our sample using the specification in column 4 of Table 2.[12] We provide a map of estimated parcel-specific irrigation premiums in Figure 4. We find a pattern of the highest premiums in the southwest and southcentral portion of the state, consistent with these counties having large corn and soybean yields and also having the greatest groundwater stocks. Regions in the west central and northwest portion of the Kansas High Plains Aquifer generally have a pattern of lower groundwater stocks and lower estimated premiums. Our results have

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[12] Figure A5 in the appendix provides predicted parcel-level premiums using the specification in column 1 of Table 2 (i.e., no spatial controls). Both specifications provide a similar spatial pattern of irrigation premiums.

implications for water rights retirement policies, which are increasingly being discussed as a policy option for conserving groundwater. For instance, retiring agricultural water rights has recently been discussed in the context of the impairment issue at Quivira National Wildlife Refuge within GMD 5 (Big Bend Groundwater Management District No. 5 Board of Directors, 2019). Our work is important for understanding the cost of retiring water rights. Cost-effective water rights retirement involves targeting producers having high water use and low capitalized value of irrigation. Moreover, optimal spatial targeting of water rights retirement depends on the spatial heterogeneity of the impacts of irrigation on streamflow and the spatial heterogeneity in the cost of retirement.

Repeated Sales

We investigate potential bias due to omitted variables in the hedonic estimates by exploiting repeated sales in a subsample. There are 2,269 parcels with repeated sales within our total sample of 17,312 transactions (repeat sales within the same year are dropped). Summary statistics for the repeat sales are presented in Table A2. It is worth noting that there are observable differences in mean values for some of the variables between the repeat sales sample and cross-sectional population.[13] We first treat the subsample of 2,269 parcels as pooled cross-sectional. Column 1 of Table 4 presents results using township and year-quarter dummies. The result of most interest is the average marginal value of water in-storage. Treating the subsample as a pooled cross-section with township dummies, we obtain average marginal valuation of $7.01/ft, which is about twice as large as the average marginal effect obtained from the full dataset. This difference

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[13] Mean values between the full cross-sectional population and the repeat sales sample are compared by irrigation status using a t-test. The t-test indicates there are statistically significant differences in some of the variables.

is likely due to observable differences in parcel characteristics between the repeat sales sample and cross-sectional population (Tables 1, A2).

Column 2 includes parcel-level fixed effects. When unobserved parcel-level heterogeneity is controlled for, estimates for the average marginal value of water in-storage increases to \$11.18/ft. Columns 3 and 4 separately estimate regressions for irrigated and non-irrigated parcels, respectively. Restricting the analysis to only irrigated parcels produces an average marginal value of \$15.86/ft, but the uncertainty of the marginal value also increases because less variation is exploited with parcel-level fixed effects. By comparison, the average marginal value for non-irrigated parcels is negative and statistically insignificant (as expected). Comparing results across columns 1 and 2, our results provide evidence that the estimated value of water in-storage suffers from some downward bias if parcel-level unobserved heterogeneity is not taken into consideration. This finding is consistent with the conclusions in Buck et al (2014), who evaluate marginal valuations of surface water deliveries on California farmland sales.

Note that a major limitation to parcel fixed effects is that very few farms switch from dryland to irrigated during the period of analysis due to most areas being fully appropriated (Sampson and Perry, 2019). This effectively prevents identification of land value premiums from irrigation. One of the goals of our paper is to estimate the total value of the aquifer, so we prefer the specification that allows identification of this value.

Water Values Comparison

For Kansas, Torell et al. (1990) estimate an irrigation premium of 43% and an *average* value of water in-storage of approximately \$4.90/acre-ft.[14] They found that irrigation premiums

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[14] Torell et al. (1990) provide estimates of the average value of water in storage by dividing the estimated irrigation premium (dollars/acre) by average saturated thickness. By comparison, our marginal value is obtained from spatially-temporally varying saturated thickness measurements.

and water value fell throughout their study period (1979-1986). By comparison, we estimate a higher irrigation premium of 53% and that real irrigation premiums are increasing over time. In contrast to Torrell et al. (1990), we are able to obtain estimates of average *marginal* values of water in-storage ($3.42/acre-ft to $15.86/acre-ft). In a similar study using transaction data for a single Nebraska county, Brozović and Islam (2010) find marginal valuations of water in-storage not different from zero. One explanation for why our estimates differ from Brozović and Islam (2010) is that our data cover a much larger area with substantial variation in groundwater stocks so that we are better able to estimate the marginal value. Using equations derived from capital theory, Fenichel et al. (2016) estimate a marginal effect at the mean of an acre-ft of irrigated water that ranges from $7.00 to $17.00 in Kansas, depending on discount rate. Similarly, Addicott and Fenichel (2019) use capital theory to estimate the implied marginal valuations of water for each GMD in Kansas and find values ranging from $8.11/acre-ft to $50.97/acre-ft. Addicott and Fenichel's estimate for the statewide marginal valuation of water is $17.45/acre-ft. While our estimates are generally in line with Fenichel et al. (2016) and Addicott and Fenichel (2019), one advantage of our study is the ability to exploit actual market transactions for rights to irrigate. In contrast, Fenichel et al. (2016) and Addicott and Fenichel (2019) rely on predictions for representative revenues per acre from agriculture using yield functions (assuming median yields per acre per crop).

Using county data, Hornbeck and Keskin (2014) show that the irrigation premium for the Ogallala decreased from the 1970s to the 1980s and then remained fairly constant from 1980 to 2002. Using data from Kansas that is more detailed and more recent, we show that the irrigation premium has been increasing over time. Hornbeck and Keskin also find that the effect of access to the Ogallala on land values is higher in counties with lower average annual rainfall. Rainfall gradients in Kansas are typified as being wet in the east and dry in the west, with little latitudinal variation (Fig. A6). Differences in average county precipitation therefore do not appear to explain the heterogeneity in irrigation premiums that we find (Fig. 4). Additionally, looking at the interaction term between irrigation and average growing season precipitation in Table 2, we do not find any evidence of a statistically significant relationship between rainfall and irrigated land values. Instead, we find substantial differences in the irrigation premium corresponding to spatial differences in saturated thickness of the aquifer. We attribute these differences to having more precise controls over unobserved spatial, temporal, and spatial-temporal heterogeneity than Hornbeck and Keskin (2014). In particular, Hornbeck and Keskin (2014) do not incorporate data on saturated thickness into their model and cannot estimate the marginal value of groundwater stocks.

Alternative Functional Forms

We perform several sensitivity checks to our main analysis. In Table A3 we report coefficient estimates from a Poisson regression. The log linear regression can lead to inconsistent estimates (Silva and Tenreyro, 2006) and estimating the Poisson via maximum likelihood is a convenient alternative because multiplicative adjustments are not needed for converting partial effects and predictions from logs to levels. In sum, the results are entirely consistent with the main analysis.

Kuminoff et al. (2010) review 123 hedonic studies published between 1988 and 2008. In their review, Kuminoff et al. (2010) emphasize that flexible specifications such as the Box-Cox may outperform more common specifications like the linear or semi-log when spatial fixed effects are included. Additionally, Crouter (1987) recommends flexible methods like Box-Cox to identify functional form when water is not appurtenant to the land (i.e. separable from the land). Because water rights can be considered appurtenant to the land in our setting and unobserved spatial heterogeneity is a possibility, we use the Box-Cox procedure to test sensitivity of our baseline specification assumption. In particular, we test sensitivity of the semi-log specification of the hedonic price function.[15] Using the Box-Cox model and adapting equations (1) and (4), letting θ be the transformation parameter on the dependent variable, the regression equations for observing the real sale price per acre of parcel i in a given year are:

$$P_{it}^{\theta} = \beta_1 IRR_{it} + IRR_{it}(\beta_2 ST_{it} + \beta_{22} ST_{it}^2 + \beta_3 HC_{it} + \beta_4 w_{it}) + \beta_5 ST_{it} + \beta_{55} ST_{it}^2 + \beta_6 HC_{it} + \xi' z_{it}^{DL} + \Omega' z_i^v + \eta_l + \tau_{d,t,q} + \epsilon_{it} \tag{5}$$

where $P_{it}^{\theta} = \frac{price}{acre}$ if $\theta = 1$, $P_{it}^{\theta} = \ln\left(\frac{price}{acre}\right)$ if $\theta = 0$, and $P_{it}^{\theta} = \frac{1}{\frac{price}{acre}}$ if $\theta = -1$.

A Box-Cox regression model suggests a best fitting value of $\theta = 0.116$. We estimate the implicit premium of irrigated land relative to non-irrigated land using the optimal Box-Cox transformation and compare to the baseline semi-log. The Box-Cox transformation produces an average estimated irrigation premium of \$848/acre. By comparison, our preferred model (column 4, Table 2) produces an average estimated irrigation premium of \$988/acre. In short, both models generate similar estimates, which is not surprising given how close the optimal θ is to zero. However, estimating the hedonic model with the price and saturated thickness variables transformed via the optimal θ presents an important issue of interpretation. Here, we opt to use the Box-Cox method as guidance to one of the more economically sensible specifications.

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[15] Performing Box-Cox transformations on the focal independent variable (saturated thickness) is problematic for two reasons. First, as mentioned previously, we center the continuous independent variables for ease of interpretation of the implicit value of irrigation relative to dryland (predicted implicit irrigation premium for otherwise equivalent parcels having zero saturated thickness is neither interesting nor realistic). Second, optimal transformation of single-variable predictors then raises the question of simultaneous estimation of optimal transformations of the interactions terms that depend on those variables.

Conclusion

This paper estimates the value of irrigation premiums and the implicit marginal value of water in-storage using a hedonic pricing model and parcel-level transaction data for agricultural land sales over the Kansas portion of the High Plains Aquifer. The results of our analysis demonstrate four key points. First, irrigated lands fetch sales prices that are 53% larger than non-irrigated lands, on average. Second, irrigation premiums have been growing over time at an average rate of about 1.0 percentage points per year. Third, we identify substantial spatial heterogeneity in irrigation premiums, which generally correspond to heterogeneities in groundwater stocks. Fourth, we find that groundwater in-storage is capitalized in agricultural land prices at an average marginal valuation of \$3.42/acre-ft to \$15.86/acre-ft, depending on the resolution of spatial controls used.

The results of this study are useful to both farmland owners and policy makers as they determine policies best suited for conserving aquifer water stocks for future use, given the economic value of the water. Land is one of the most important capital assets comprising producer wealth and the availability of irrigation has important implications for land values. As water tables fall due to groundwater mining, changes in the value of the aquifer are most appropriately estimated using marginal valuations. However, changes in the perceived scarcity of groundwater may bring about changes in implicit valuations of irrigation and water stocks. Lastly, spatial heterogeneities in irrigation premiums closely match spatial heterogeneities in groundwater stocks. Understanding heterogeneity in total value of the right to irrigate is important in designing cost effective policies aimed at curtailing or retiring water use.

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Figures and Tables

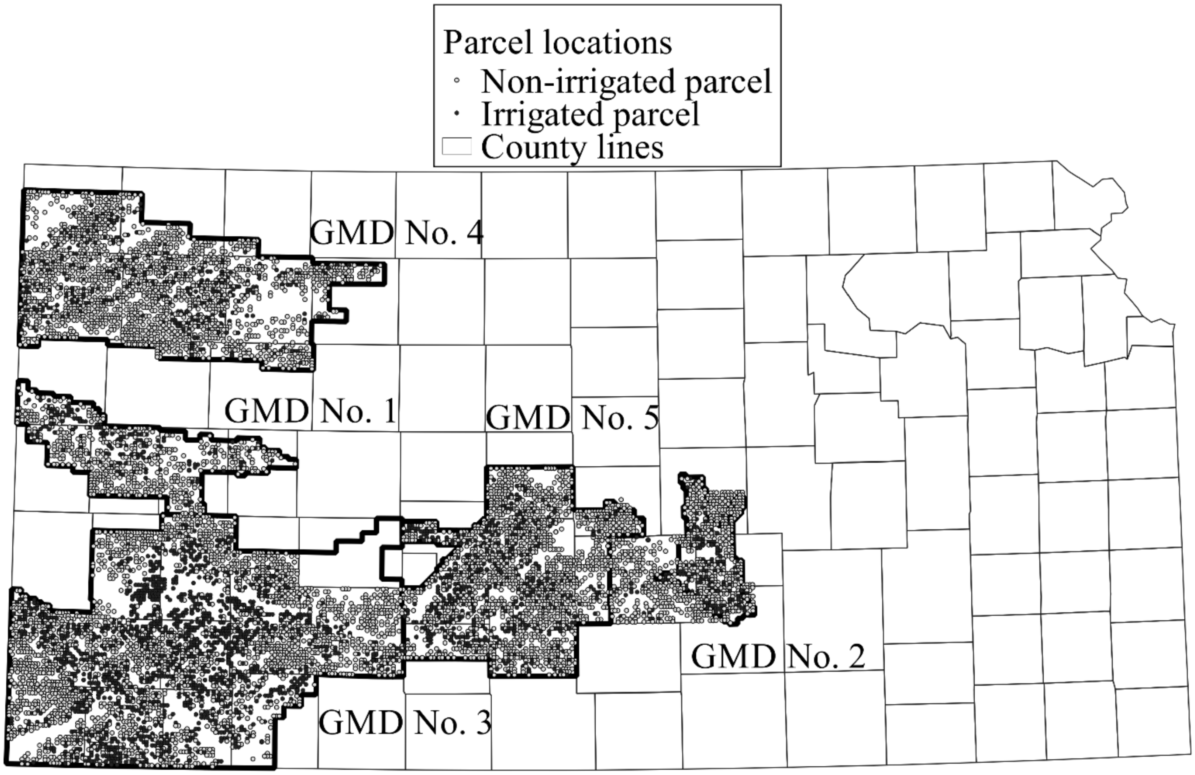

Figure 1. Parcel locations and GMD boundaries.

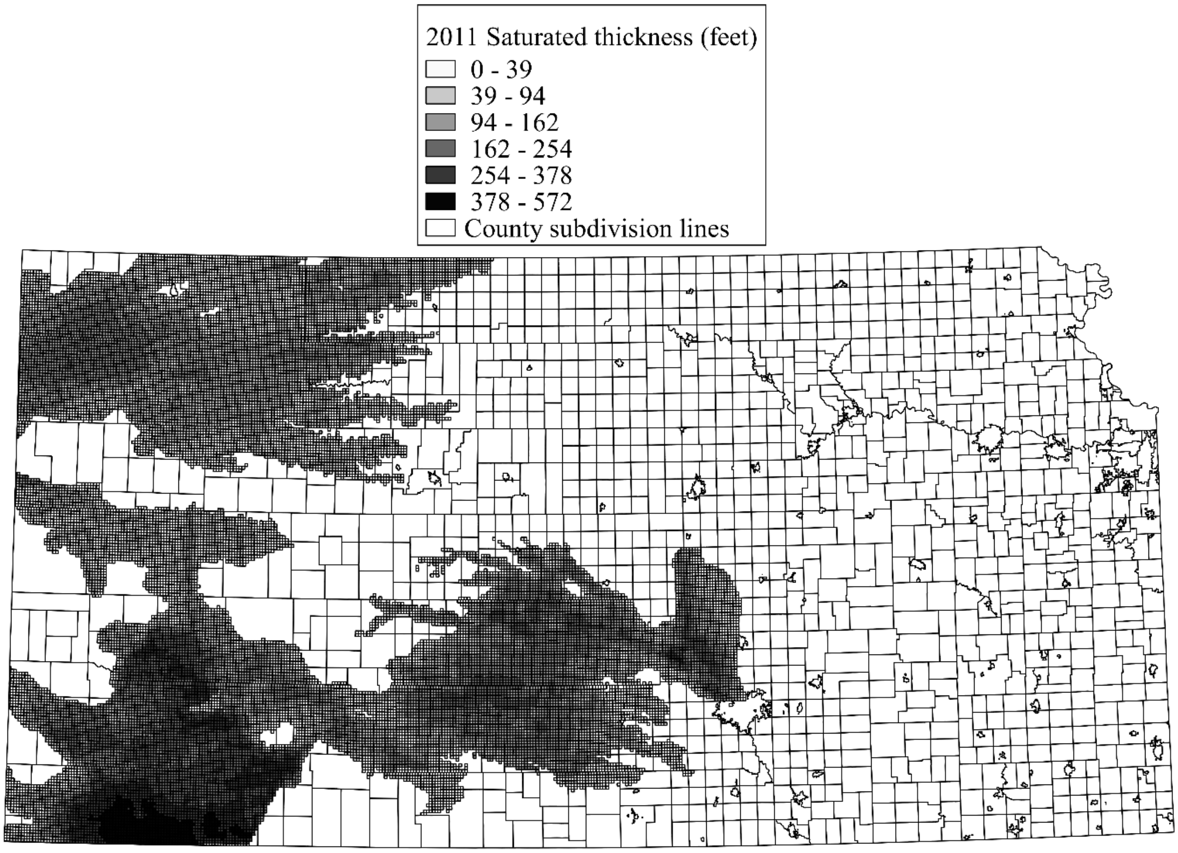

Figure 2. Saturated thickness (feet) for the High Plains Aquifer in 2011.

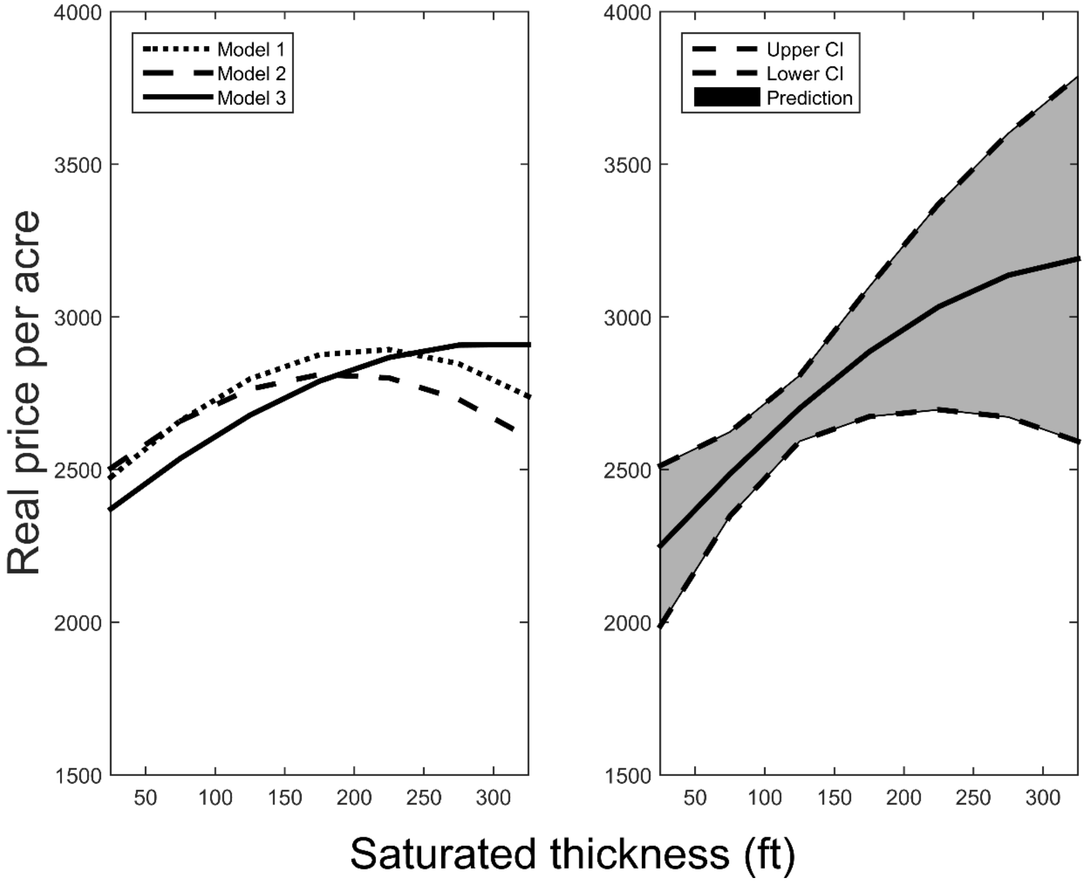

Figure 3. Predicted price per acre for different levels of saturated thickness for preferred specification with township controls (right) and alternative specifications (left).

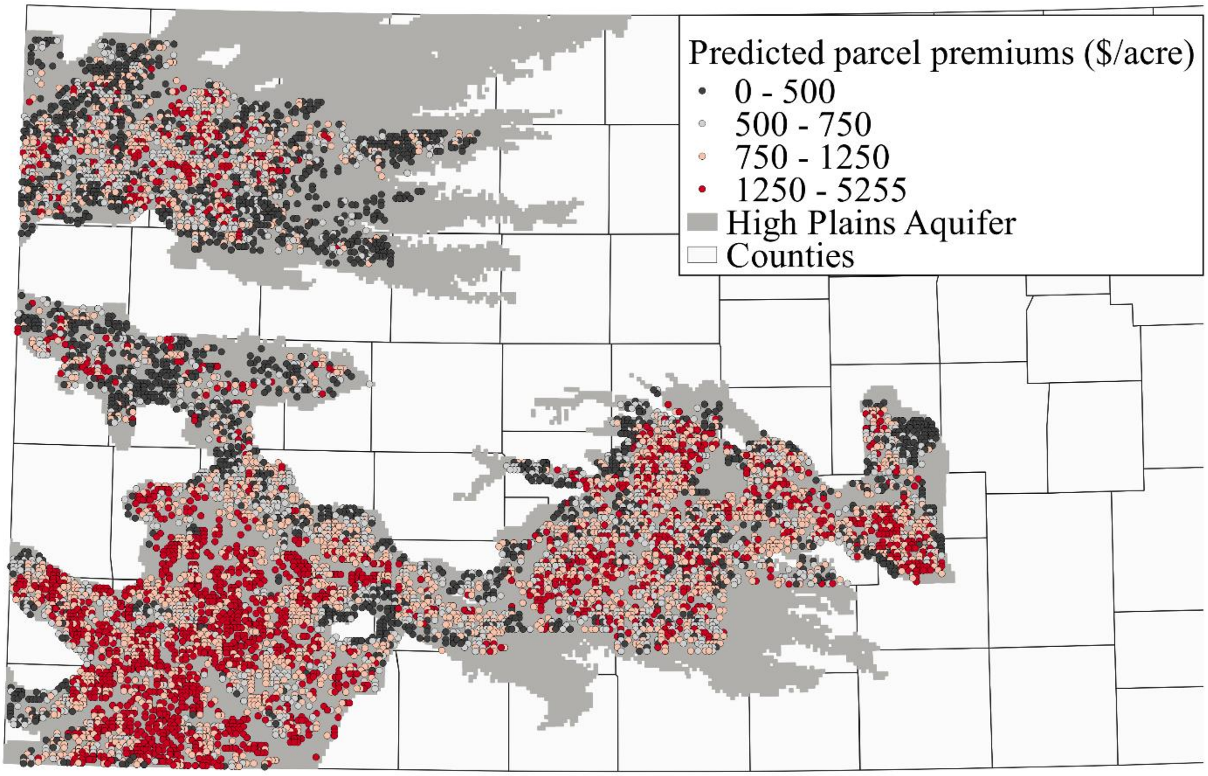

Figure 4. Predicted irrigation premium by parcel.

Table 1. Summary statistics

Variable (units)	Irrigated				Non-irrigated			
	Mean	Std.D	Min	Max	Mean	Std.D	Min	Max
Price per acre ($/acre)	2,811.8	2,175.8	57.1	9,982.1	1,681.4	1,638.2	35.6	9,977.4
Hydraulic Conductivity (ft/day)	77.7	26.7	14.0	120.0	77.7	27.8	13.0	122.0
Saturated thickness (ft)	167.2	106.7	1.0	562.4	91.5	87.1	0.0	564.1
Authorized quantity (in/acre)	13.0	6.1	0.5	24.0	0.0	0.0	0.0	0.0
Commute time to 10,000 population (hrs)	0.9	0.5	0.1	2.8	1.0	0.7	0.1	2.8
Commute time to 40,000 population (hrs)	2.6	0.9	0.2	4.0	2.3	1.0	0.1	4.1
Root Zone Available Water Storage (mm)	252.5	60.0	80.0	335.0	267.1	49.0	34.0	335.0
Soil Organic Carbon (kg/m^2)	8,091.8	3,075.6	903.2	24,249.0	9,280.3	2,843.4	1,186.2	19,862.1
Acidic soils (proportion of land)	0.2	2.5	0.0	75.0	0.1	2.0	0.0	66.7
Basic soils (proportion of land)	67.8	40.3	0.0	100.0	68.9	39.9	0.0	100.0
Growing season precipitation (inches)	15.4	2.6	12.5	23.8	16.4	2.9	12.5	23.8
Evapotranspiration (inches)	36.2	1.2	32.4	38.1	35.7	1.2	32.3	38.1
Degree days between 10 and 32 Celsius (degrees*days)	1,987.7	109.6	1,643.2	2,181.3	1,962.2	137.1	1,643.2	2,188.3
Degree days over 32 Celsius (degrees*days)	47.1	7.2	23.0	63.7	44.5	7.5	23.0	68.3

Table 2. Regression results for hedonic model.

	(1)	(2)	(3)	(4)
Irrigated parcel	0.560***	0.549***	0.590***	0.532***
	(0.051)	(0.048)	(0.045)	(0.054)
Irrigated parcel interacted with saturated thickness (hundreds of ft)	0.0733**	0.0916***	0.124***	0.125***
	(0.033)	(0.026)	(0.023)	(0.031)
Irrigated parcel interacted with square of saturated thickness (hundreds of ft)	-0.025	-0.0219	-0.021	-0.00279
	(0.027)	(0.027)	(0.024)	(0.023)
Saturated thickness (hundreds of ft)	-0.0325	-0.0718**	-0.0513	-0.00353
	(0.031)	(0.036)	(0.038)	(0.045)
Square of saturated thickness (hundreds of ft)	-0.019	-0.021	-0.006	-0.030
	(0.025)	(0.025)	(0.023)	(0.025)
Hydraulic conductivity	-0.00122	-0.00126	-0.00191*	-0.00132
	(0.001)	(0.001)	(0.001)	(0.001)
Time to 10K population center	0.443	-0.225	0.100	-0.493
	(0.402)	(0.311)	(0.616)	(0.561)
Time to 40K population center	-0.0898	-0.195	1.206	0.0461
	(0.227)	(0.305)	(0.744)	(0.448)
Average growing season precipitation	-0.024	-0.002	0.014	-0.103
	(0.043)	(0.036)	(0.083)	(0.079)
Reference evapotranspiration	0.117	-0.007	0.093	0.191
	(0.098)	(0.120)	(0.227)	(0.334)
Degree days between 10 and 32 Celsius	0.001	-0.00241*	0.000	0.00704*
	(1.00E-03)	(0.001)	(0.003)	(0.004)
Degree days over 32 Celsius	-0.0265**	0.0165	0.00769	-0.0925*
	(0.013)	(0.019)	(0.037)	(0.050)
Root zone available water storage	8.05E-04	4.76E-04	-6.49E-05	3.97E-04
	(8.80E-04)	(8.02E-04)	(8.56E-04)	(8.93E-04)
Soil organic carbon	0.0228***	0.0205***	0.0216**	0.0218**
	(0.007)	(0.007)	(0.010)	(0.010)
Acidic soils	0.003	0.00597	0.00385	0.00677**
	(0.004)	(0.004)	(0.003)	(0.003)
Basic soils	0.001	1.18E-04	0.00163**	2.46E-04
	(6.83E-04)	(5.79E-04)	(6.40E-04)	(6.73E-04)
Other variables interacted with irrigated parcels				
Hydraulic conductivity	0.00144*	0.00160**	0.0014	0.00202*
	(8.02E-04)	(7.86E-04)	(8.97E-04)	(0.001)
Authorized inches per acre	-9.03E-05	-7.03E-04	-1.28E-04	0.003
	(0.003)	(0.003)	(0.003)	(0.004)

Average growing season precipitation	-0.020	-0.038	0.017	0.003
	(0.039)	(0.037)	(0.039)	(0.050)
Reference evapotranspiration	-0.018	-0.084	0.059	-0.033
	(0.113)	(0.104)	(0.130)	(0.144)
Degree days between 10 and 32 Celsius	-6.23E-05	-6.26E-04	4.17E-04	-9.56E-04
	(8.03E-04)	(5.54E-04)	(9.82E-04)	(7.46E-04)
Degree days over 32 Celsius	0.008	0.020	-0.007	0.020
	(0.018)	(0.015)	(0.024)	(0.022)
Root zone available water storage	-1.47E-03	-0.00164*	-0.002	-0.001
	(9.26E-04)	(8.69E-04)	(9.66E-04)	(0.001)
Soil organic carbon	-0.011	-0.003	-0.005	-0.008
	(0.011)	(0.011)	(0.010)	(0.013)
Spatial Controls	None	County (36)	County Subdivisions (240)	Township (603)
Observations	15,295	15,295	15,295	15,295
Irrigated saturated thickness (hundreds of ft) average marginal effect	118.7	59.2	200.2**	342.2**
	(106.5)	(106.1)	(99.1)	(139.3)
Non-irrigated saturated thickness (hundreds of ft) average marginal effect	-11.6	-72.6	-69.2	60.0
	(73.7)	(74.0)	(96.6)	(103.6)

Standard errors clustered at counties in parenthesis

*** p<0.01, ** p<0.05, * p<0.1

Controls for GMD by year by quarter dummies

Table 3. Regression results for time-variant models.

	(1)	(2)
Irrigated parcel	0.364***	0.406***
	(0.104)	(0.083)
Variables interacted with irrigated parcels		
GMD No. 1 trend (irrigated)		-0.00454
		(0.006)
GMD No. 2 trend (irrigated)		-0.008
		(0.006)
GMD No. 3 trend (irrigated)		0.010
		(0.007)
GMD No. 4 trend (irrigated)		0.00338
		(0.006)
GMD No. 5 trend (irrigated)		0.0129***
		(0.004)
Statewide trend (irrigated)	0.0098*	
	(0.006)	
Saturated thickness (hundreds of ft) average marginal effect	351.7**	377.4***
	(152.7)	(133.0)

Standard errors clustered at county level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Controls for all other variables from Table 2. Model 1 controls for GMD by year by quarter effects. Model 2 controls for year by quarter effects

Table 4. Regression results for parcels with repeated sales.

	(1)	(2)	(3)	(4)
Irrigated parcel	0.493***	0.414		
	(0.079)	(0.946)		
Saturated thickness (hundreds of ft)	0.194***	0.493	0.540**	-0.634
	(0.070)	(0.548)	(0.265)	(0.675)
Square of saturated thickness (hundreds of ft)	0.0867	-0.158	-0.149*	-0.237
	(0.073)	(0.246)	(0.089)	(0.411)
Year X Quarter Controls	Yes	Yes	No	No
Year Controls	No	No	Yes	Yes
Spatial Controls	Township (478)	Parcel (2,268)	Parcel (796)	Parcel (1,256)
Sample	All repeat sales	All repeat sales	Irrigated repeat sales	Non-irrigated repeat sales
Observations	4,306	4,844	1,751	3,093
Saturated thickness (hundreds of ft) average marginal effect	701.1*	1,117.7*	1,585.9**	-377.3
	(371.9)	(630.8)	(774.4)	(1313.1)

Standard errors clustered at counties in parenthesis
*** p<0.01, ** p<0.05, * p<0.1