Estimating the Demand for In-situ Groundwater for Climate Resilience: The Case of the Mississippi River Alluvial Aquifer in Arkansas[1]

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Abstract

Knowledge of the demand for in-situ groundwater can help policy makers understand the value of groundwater to farmers experiencing climatic change. A drier and hotter climate will shift outward the demand for groundwater in storage, and the shift has implications for agricultural property values. The empirical magnitude of the shift is what we measure in this paper. Using fine scale data from Eastern Arkansas, overlaying the Mississippi River Alluvial Aquifer, and a unique farm-level irrigation survey, a second-stage hedonic framework recovers the underlying demand function for groundwater as measured by saturated thickness. Instruments based on the principle of Tiebout sorting and variables from the irrigation survey address the second-stage endogeneity concerns that arise in the identification of the inverse demand parameters. An inch decrease in expected rainfall during the growing season due to climate change increases the per acre value of irrigated farmland with an average 120 feet saturated thickness by $294 to $336 depending on the agricultural land market.

Keywords: groundwater, climatic change, sustainability

JEL codes: Q15, Q25, Q20

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[1] The findings and conclusions in this manuscript are those of the authors and should not be construed to represent any official USDA or U.S. government determination or policy.

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1. Introduction

Groundwater systems are connected to climate change and variability both through natural recharge and through changes in the use of groundwater. Those impacts depend on human choices such as changes in land use. Since groundwater is a common source of high-quality fresh water, there is frequent development of the resource which can easily scale to meet local needs without a major need for infrastructure (Giordano 2009). Throughout the world, groundwater supplies a third of freshwater for domestic use, more than a third for agriculture use, and nearly a third for industrial use (Doll 2012). In periods low or absent rainfall, the groundwater will naturally replenish the baseflow of waterbodies such as streams and wetlands. While certainly crucial to natural and human systems, there is general lack of studies on the relationship between climate, groundwater, and its monetary value that restricts how well the Intergovernmental Panel on Climate Change (IPCC) can assess human impacts related to climate change. The value of in-situ groundwater is difficult to measure because there is no market for the resource, and this complicates the evaluation of climate impacts on groundwater value. We propose to examine how the value of groundwater changes with climate using the relationship between agricultural land values and saturated thickness in the Lower Mississippi River Basin in Arkansas, USA.

The inverse demand for groundwater that we recover through the second-stage hedonic analysis (Bartik 1987; Zhang et al. 2015) depends on the quantity of groundwater and demand shifters such as farm and demographic characteristics (e.g. education level, income and size of the farm operation, experience of household members), environmental conditions (e.g. soil quality, precipitation), and information on irrigation from social interaction with other farmers or farm specialists. A change in human capital, such as the years of formal education, or in social capital, such as the use of an irrigation practice by family and friends, can shift the inverse demand for groundwater. A downward shift implies the other capital decreases the shadow price for groundwater (i.e. substitution) while an upward shift means the other capital increases the shadow price for groundwater (i.e. complement). Fenichel et al. (2016) derive the demand for groundwater for the Kansas High Plains Aquifer and find that a rise in a water-efficient drop nozzle technology shifts the demand downward. The downward shift showed a substitution between natural capital (i.e. groundwater) and produced capital (i.e. water-efficient drop nozzle technology). Similar to Rad et al. (2021) and Yun et al. (2017), we use shadow prices for natural capital to examine substitution and complementarity, but the shadow prices come from a hedonic model. The demand equation derived from the hedonic analysis can answer the call to empirically measure the relationship between natural capital and other forms of capital rather than assume them (Rad et al. 2021; Cohen et al. 2019).

The Mississippi River Valley Alluvial Aquifer (MRVA) is the primary irrigation source for the Mississippi River Delta agricultural region. The largest user of the alluvial aquifer is Arkansas where withdrawals are more than 7 billion gallons per day (primarily for rice, soybeans, and corn), and more than half of those withdrawals represent overdraft (ADA 2021). The most recent water plan by the state of Arkansas (ANRC 2015) lists “declining groundwater levels and the need to move toward sustainable use” as a priority issue. The overdraft of the groundwater lowers the value of agricultural land, and the losses will increase if the climate become drier and hotter. Policies to mitigate overdraft come at a substantial cost for agricultural producers and taxpayers (Schaible and Aillery 2012), and information about the benefits of groundwater conservation, especially non-marginal changes, can help determine the scope of the policy response to overdraft with a changing climate.

The owners of the land above the groundwater likely receive a substantial benefit from the aquifer from year round access to the groundwater for provisioning services. These owners of the land may operate the land themselves or may lease the land to operators for extractive activities. Landowners implicitly pay for the benefits of groundwater by purchasing land that is more expensive than similar land without access to the underlying aquifer. A one foot increase in saturated thickness (e.g. the cross-sectional height of water-bearing rock) has been found to increase agricultural land value above the Ogallala aquifer from $0 to $17.21 (Brozovic and Islam 2010; Sampson et al. 2019; Torell et al. 1990) and in the Sacramento Valley of California by $342 (Bigelow et al. 2019).[4]

The emphasis in the hedonic property value literature of groundwater has been identifying the marginal willingness to pay (WTP) through point estimates. The aim of welfare analysis though is often to find the value of non-marginal changes in a non-market good, and Rosen (1974) proposed to use the point estimates from the hedonic model to recover an inverse demand function. In the context of groundwater, after finding the implicit prices of groundwater, the second step would be to use the implicit prices as the dependent variable in an inverse demand function explained by the quantity of groundwater and a set of demand shifters. Identification difficulties are encountered however in this two stage process.

One identification problem is that without additional data the inverse demand function estimation can do no more than reproduce the coefficients in the hedonic price equation (Brown and Rosen 1982). Choosing a functional form for utility has been used to separate the effects of demand

[4] All dollar estimates in this paper are put into 2019 dollars using the GDP Implicit Price Deflator.

shifters and quantity change on the implicit price (Chattopadhyay 1999; Kuminoff 2009). However, we use the following two alternative approaches. First, imposing non-linearity in the hedonic price gradient through a flexible parametric model helps to overcome the identification problem (Ekeland et al. 2004). Second, we estimate separate hedonic price functions for multiple segmented markets and suppose no unobservable differences in preferences across landowners (Bartik 1987; Zabel and Kiel 2000; Bishop and Timmins 2019). In the multiple market approach, the different implicit prices in the markets are solely the result of a representative landowner facing different quantities of groundwater. However, the assumption that preferences and income are similar in all markets has been challenged by research showing that people sort themselves through their tastes (Banzhaf and Walsh 2008).

This leads to the other identification problem in estimating the inverse demand function, which is that the quantity of groundwater and the implicit price are endogenous. The point chosen by the landowner on the hedonic price schedule simultaneously determines the implicit price and the quantity of groundwater rather than the situation of an exogenously set price followed by the selection of a quantity. A challenge is to find truly exogenous variables for instruments, variables uncorrelated with the implicit price of groundwater but sufficiently related to saturated thickness. We draw on instruments suggested by the literature on residential sorting (Epple and Sieg 1999; Klaiber and Kuminoff 2014) and on instruments from survey responses by irrigators in the Arkansas Delta.

We make several contributions to the literature on climate and groundwater. First, we provide empirical evidence for the decrease in the value of agricultural land due as overdraft intensifies as the climate starts to heat and dry above current levels. Second, we estimate a non-marginal WTP for groundwater using the revealed preference hedonic property value method. Using the consumer surplus from the uncompensated demand, the WTP for a foot increase in saturated thickness is \$4.70 and \$24.80 for all farms and rice farms, respectively, when current thickness is between 100 to 120 feet. Third, we show that the demand slope is heterogeneous, in particular the demand for in-situ groundwater is more elastic for rice farmers than for all farm landowners.

2. Theoretical model

Consider the rents flowing to a landowner from an acre of irrigated cropland at time *t*, $R(N(t), K(t))$, from the utilization of the natural capital (i.e. groundwater and other natural resources), $N(t)$, and from climate resources, $K(t)$. The net present value of rents (Eq. 1), which equals the fundamental value for the land, is

$$\boldsymbol{V(\cdot) = \int_t^{\infty} e^{\delta(\tau - t)} R(N(\tau), K(\tau)) d\tau,} \tag{1}$$

where the discount factor $e^{\delta(\tau-t)}$ puts the flow of rents over the infinite planning horizon into period *t* values. The shadow price of the natural capital (i.e. the asset price or accounting price) shown in Eq. 2 is

$$p^N = \frac{\partial V(\cdot)}{\partial N(t)}. \tag{2}$$

The shadow price is the gain the landowner receives in perpetuity for a marginal increase in the stock of the natural capital. The shadow price for the natural capital depends on the discount factor, existing institutions (e.g. government support and conservation programs), and the physical characteristics of the natural system (Yun et al. 2017).

The hedonic price function for agricultural land reveals the shadow prices of the characteristics of the land, which include the natural capital, since the sale value of the land in a well-functioning market is the net present value of the rents that depend on the characteristics in $N(t)$

and $K(t)$. Rosen (1974) examines how to estimate a property owner's marginal bid function for characteristics of a property given estimates from the hedonic price function. The bid function gives information about the property owners because in equilibrium a property owner's marginal bid for the characteristic, i.e. natural capital, equals the marginal price of the characteristic at the property owner's chosen land type. Consider a general version of the marginal bid function (Eq. 3),

$$p^N = B(\boldsymbol{D}(x(N,K))), \tag{3}$$

which depends on a vector of observed demand traits, $\mathbf{D}$, affecting the marginal bid. Some of the traits relate to producer's management decisions shown as $x(K,N)$ which respond to the evolving stocks of natural capital and climate resources. If there is a shift in climate resources, Eq. 4 shows the shadow price of the natural capital stock after the shift,

$$p_S^N = B(\boldsymbol{D}(x(N^S,K^S))). \tag{4}$$

With the inverse demand for the natural capital, the case of $p_S^N > p^N$ implies that natural capital and climate resources are complements while $p_S^N < p^N$ indicates that the two are substitutes.

3. Case study: Groundwater in the Arkansas Delta

We use the responses of a 2016 sample of irrigators in the Arkansas Delta to test whether precipitation changes through a drier and hotter climate affect the shadow price of the saturated thickness of an aquifer, the natural capital stock. Arkansas is the largest user of the Mississippi River Valley Alluvial (MRVA), which is the third most used aquifer in the USA (Konikow, 2013). A substantial rise in irrigated land, especially rice, has led to a tenfold increase in groundwater usage from the MRVA from 1950 to 2010 (Kresse et al., 2014). An extensive part of the region has seen groundwater levels decline to less than half of the pre-settlement aquifer thickness (Clark et al., 2013). Cones of depression from the over-draft of groundwater have led to the designation of critical groundwater areas (ADA 2021).

Government agencies such as the Natural Resources Conservation Service are looking at a system approach in promoting on-farm water conservation practices, which emphasizes the use of multiple practices to improve various parts of an irrigation system (e.g., irrigation, conveyance, water storage, release of water from farm, Sullivan and Delp, 2012). For example, a rice farmer in Arkansas can use alternate wetting and drying irrigation of rice to drain a field intermittently through the rice life-cycle rather than continuously flood the field, which can generate average water savings from 20 to 70% (Nalley et al. 2015). In addition, the farmer can augment water supply on farm by building a tail-water recovery system and on-farm reservoir to capture water released from flooded fields and rainfall runoff and store them for future irrigation (Kovacs et al. 2015). The farmer can reduce water use further by adding other practices such as flow meters (for monitoring and managing the flow control of irrigation sources) and soil moisture sensors (Nian et al. 2020). Encouragement of a system approach gets producers to think about a set of water conservation practices, and farmers gain social capital by observing the use of irrigation techniques within their peer network.

3.1 Data

We combine agricultural land transactions, farm operator characteristics, and groundwater data from numerous sources to estimate empirically the demand for saturated thickness. The agricultural land sale information come from the county land records for Arkansas (DataScout LLC 2020). The sale price and date for each agricultural land transaction that overlays the MRVA in Arkansas between 1993 to 2019 and is greater than 10 acres in size has a unique identification number for the parcel (Figure 1). We use the deed type to screen out the agricultural land transactions that are not arms-length to eliminate bias from sales with ownership by multiple families. Any transactions where the total assessed value exceeds the land assessed value are also removed to avoid bias from unobserved structural improvements to the agricultural land. Also we exclude transactions with 2019 dollar sale prices per acre greater than the 95th percentile or below the 5th percentile to reduce the influence of outliers. In total there are 4,701 agricultural land transactions.

A geographic information system is used to link a parcel identification number to a spatial coordinate for each property. To identify parcels that irrigate, we suppose the parcel must have an irrigation well based on spatially explicit well construction and hydrology characteristics for the MRVA from the Arkansas water well construction commission (WWCC). Owners of any well drilled in the state must submit to the WWCC the location coordinates, pumping capacity, and designated use of the well. We expect parcels with a well on property, or near the property, to have a lower price per acre because the groundwater is likely to be depleted beneath the parcel. We use dummies for well on parcel, quarter mile of parcel, and half mile from a parcel to explore this hypothesis. The calculation of the saturated thickness is the difference between the depth to the bottom of aquifer from the US Geologic Survey (USGS) and the three year rolling average depth to the saturated region of the aquifer[5] from the Arkansas Department of Agriculture, Division of Natural Resources. Figure 2 shows the saturated thickness in 2010, and our calculations are consistent with the Arkansas Department of Agriculture and USGS methods

[5] If the sale of agricultural land occurred between January and May, we associate to the parcel the saturated thickness value from the preceding year. We find our results are robust to other approaches to attach saturated thickness to parcel transactions, including the previous year depth and five year rolling average measures.

for the estimation of saturated thickness. Saturated thickness largely declined over the time frame of the analysis, but some sub-regions have seen a recovery (Figure A1).

Lateral hydro-conductivity within the alluvial aquifer comes from the spatial interpolation of slug tests by the USGS for forty-two wells. Despite the limited lateral hydro-conductivity measurements, the hydro-conductivity does not change significantly over space and presumably will not require many wells to detect accurately. The spatially explicit intermittent stream or river features come from the National Hydrology Dataset. Water infrastructure other than wells near to parcels could also influence irrigation returns and productivity. Spatial detail for on-farm water storage such as reservoirs or tail-water recovery systems come from West and Kovacs (2018). Soil characteristics also affect the rents to parcels and the data are from the on-line SSURGO soil survey with the USDA Natural Resources Conservation Service. The soil characteristics representing crop productivity and water storability include: the root available water storage, the soil organic matter, and percentage of the parcel land with a soil pH less the 5.3 (acidic soils for the Arkansas Delta).

Daily gridded weather data merged to the parcels come from the PRISM, and we construct four weather variables to understand how recent weather affects the parcel sale: growing season precipitation for the previous year before the sale and the previous three year average, the average number of degree days between 10 and 32 °C in the past five years, and the average number of degree days when heat harms crop growth (i.e. above 32 °C) in the past five years (Schlenker et al. 2005). The controls for urban influence include the commute times to towns with greater than 5,000 in population and greater than 40,000 in population. The commute times are calculated with the ArcGIS Network Analyst tool. We use a dummy variable to indicate the sale of parcels greater than 100 acres since institutional investors often prefer large parcels. The summary statistics and descriptions of the variables for transactions with and without a well on parcel are given in Table 1.

The multiple market approach for the identification of the demand function involves the separate estimation of the hedonic price function for each agricultural land market. This means defining different agricultural land markets to place the agricultural land transactions. The Mid-South Land Values and Lease Trend Reports classify agricultural land spatially mainly by differences in soil and crop types but also by water availability and the infrastructure for irrigation and drainage, and we use these classifications to define the agricultural land markets (ASFMRA 2020; 2021). In Figure 3 we show the four agricultural land markets for our analysis[6] and the location of parcels where rice was grown at least once in the five years before the sale. The parcels where rice was grown were determined with the Cropland Data Layer (Johnson and Mueller 2010). Parcels with rice appear throughout eastern Arkansas, but there is a concentration in markets 1 (i.e. the central region known as the Grand Prairie) and 3 (i.e. the northeastern region). To examine heterogeneity in the demand for groundwater across the crop production region, we use the delineator of whether rice was grown on the parcel in the past five years to distinguish land transactions where irrigation likely has greater intensity.

The estimation of the inverse demand equation involves combining information from first stage results with survey responses from farm landowners. The Mississippi State University Social Science Research Center administered the survey in the fall of 2016 via phone interviews. The questionnaire had about 150 questions and took respondents (i.e. farm landowners who irrigate from the MRVA in Arkansas) between 30 to 40 minutes to finish on average. Of the accessible

[6] We explored a larger number of groupings for the agricultural land markets than the four in Figure 3. We split the region into six and eight agricultural land markets, respectively. The implicit price of saturated thickness for the parcels are largely robust to these different groupings for the agricultural land markets.

contacts, 624 were eligible to complete the survey, but only 199 producers completed the survey in full for a response rate of 32%. The surveys used in the second stage analysis are those from farm landowners in the Arkansas Delta: 182 observations. The surveyed farms have more irrigated acres and lower household income than the Census of Agriculture (Table 2).

Respondents of the survey answer questions about (1) their farm's water sources for irrigation and perceptions of groundwater shortage, (2) their farm's use of surface water storage and type of irrigation system (e.g. gravity versus sprinkler), (3) their farm's irrigation techniques and farm practices to conserve soil moisture, (4) willingness to pay to purchase water from an irrigation district or invest in surface water storage, (5) features of the farm and participation in conservation programs, and (6) their socioeconomics characteristics. The features of the farm include the number of irrigated acres, and the socioeconomic characteristics are income, education, and whether peers like family and friends used twelve different irrigation techniques in the last 10 years. Farmers in the region usually do not know the depth to the groundwater, and we estimate saturated thickness using the survey responses based on the county where the farmer lives, the crops grown on the farm, and whether the farm has a reservoir. The same explanatory variables are in the first stage data, and the coefficient estimates for the prediction of saturated thickness from the first stage are in Table A1. The prediction equation determines the saturated thickness for the farms in the survey. Lastly, the variables for the available water storage and precipitation used in the first stage are matched to survey responses based on the county. Summary statistics for the variables used as demand shifters and instruments in the second stage model are in Table 2.

4 Empirical approach: The second-stage hedonic analysis

4.1 Partial identification of the demand for groundwater

Recovery of a buyer's bid curves for a nonmarket good in the hedonic property value model requires going beyond the point estimates of marginal WTP. Identification problems arise since buyers of land above an aquifer choose the quantity of groundwater they will use and the price they pay for that groundwater simultaneously (Bartik 1987). The traditional approach of using exogenous shifts in the supply curve to trace out the demand curve is invalid (Brown and Rosen 1982; Epple 1987). A shift in supplier characteristics means a movement along the hedonic price function, and the consequence is positive bias, due to correlation with unobservable tastes, in the slope estimate of the buyer's bid function (see Figure 1 in Zhang et al. (2015)).

Partial identifying power to address the demand slope bias include the non-linearity of the price gradient and the use of multiple markets. Hedonic models in a single market can be identified, provided the hedonic price gradient is non-linear (Ekeland et al. 2004). Observable farmer characteristics (e.g. income) shift the groundwater demand intercept in a linear fashion, while the groundwater desired by buyers beneath the farmland adjusts in a non-linear fashion, and the covariance between the groundwater and the farmer characteristics helps identify the slope parameter (Bishop and Timmins 2019). Several sources of identifying variation come from the use of multiple markets with the cross market restrictions that all parameters of the demand function are identical across markets.

For estimation with data from multiple markets, partial identifying variation comes from three sources. The first is the sensitivity of market-specific averages for groundwater to price gradient differences across markets. For instance, suppose the average landowner use of groundwater is considerably smaller in a market with a large implicit price of groundwater, then this identifies a relatively steep marginal WTP slope. However, in the case that inverse demand has intercepts that vary by market, which is the case in our baseline specification, then the market variation in the average landowner use of groundwater will not contribute to the identification of the demand slope. Second and third, the sensitivity of cross market differences in i) covariances between groundwater and farmer characteristics and ii) variances of groundwater to differences in the hedonic price gradient across markets help in identification (Bishop and Timmins 2019). A loosening of cross market restrictions to permit variation in the non-slope coefficients on farmer characteristics and the variances of groundwater across markets would remove those sources of partial identifying variation.

The problem with assuming the parameters of the demand function are the same across markets is sorting behavior (Kuminoff et al. 2013). Landowners with strong preferences for groundwater choose to buy land where groundwater is more abundant, and landowners with similar preferences for groundwater live close to each other. The stratification leads to variation in the market being correlated with unobserved demand preferences, positively biasing the demand slope parameter (Banzhaf and Walsh 2008). However, the partial identification mentioned above is possible and allows for estimation of a one-sided bound on the parameter of the demand slope, namely the actual slope must be less than most negative estimate (Nevo and Rosen 2012).

4.2 Estimation of first-stage implicit prices and the second-stage demand for groundwater

The estimation of the hedonic price function for each of the four land markets, with the index *j*, in the sample uses the following functional form,

$$\begin{aligned}\ln P_{it} = \beta_{0j} + \beta_{1j}S_{it} + \beta_{2j}S_{it}^2 + \beta_{3j}S_{it}^3 + \beta_{4j}W_{it} + \boldsymbol{\eta}_j^{'}\mathbf{z_{it}} + \mathbf{v}_j^{'}\mathbf{x_i} + \tau + \theta_{c,t,q} \\ + W_{it}(\beta_{5j}S_{it} + \beta_{6j}S_{it}^2 + \beta_{7j}S_{it}^3 + \beta_{8j}H_i + \beta_{9j}R_{it} + \beta_{10j}PR_{it}) + \varepsilon_{it}\end{aligned} \quad (1)$$

Estimation of (1) is through a generalized linear model with a log-link function (i.e. the average of the dependent variable is transformed rather than all observations of the dependent variable) to avoid bias from the OLS estimation of the log-linear model (Sampson et al. 2019). The natural log of the price per acre of parcel *i* sold during period *t* is $\ln P_{it}$, and the saturated thickness of the MRVA aquifer is S_{it}. To test the appropriate functional form for the hedonic model (Cropper et al. 1988; Kuminoff et al. 2010), we use the Box-Cox functional form in each land market and find the log of price provides the best fit statistically for each market.

We allow for a non-linear marginal value of stock of groundwater by specifying a cubic form for saturated thickness. We also experimented with a natural log form for saturated thickness, but the cubic form was favored for its greater flexibility. We define W_{it} as a dummy variable taking on the value of one if there is an irrigation well on the parcel *i* in period *t*. Since the literature has not established how the spatial proximity of a well interacted with saturated thickness affects property value, we considered other spatial thresholds (i.e. quarter mile and half mile) for the interaction with saturated thickness and evaluated the first stage estimates. The vector $\mathbf{z_{it}}$ comprises various weather and other time-varying characteristics (e.g. recent precipitation, number of degree days, proximity of nearby wells or reservoirs to a parcel) while time invariant characteristics (e.g. commute time to population centers, proximity to streams, soil attributes, and lateral hydro-conductivity) are in the vector $\mathbf{x_i}$.

Spatial fixed effects, τ, control for unobserved heterogeneity in land prices that do not vary over time, and we explore the scale of spatial fixed effects from no controls to county subdivision controls. We also tried a specification with parcel fixed effects (i.e. the finest level of spatial fixed effects), but found the much smaller sample no longer representative of the population. Critical groundwater areas (CWA) defined by the state (ADA 2021) by year by quarter dummies, $\theta_{c,t,q}$, are in all specifications to control for commodity price movements and water management rule changes that could affect CWAs differently over time. Aquifer features (S_{it} and lateral hydro-conductivity H_i), irrigation infrastructure like reservoirs (R_{it}), and weather such as the previous year precipitation (PR_{it}) can affect the price per acre of a parcel differently if there is a well on the parcel.[7] We hypothesize the presence of a well tunes buyers into concerns about the availability of groundwater, and this affects the land value associated with water sources (i.e. aquifer, on-farm reservoirs, or precipitation). The subscript *j* on β, $\boldsymbol{\eta}$, and $\mathbf{v}$ indicate that these coefficients, which determine the shape of hedonic price function, are estimated for each land market. Lastly we account for heteroscedasticity from spatially correlated errors by allowing for intragroup correlation using counties for the clusters.

The effect of saturated thickness on agricultural land prices is likely non-linear as improvements in saturated thickness have greater well yield benefits when saturated thickness is low (Foster et al. 2015). The implicit price of saturated thickness based on the derivative of the hedonic price equation with respect to S_{it} is,

$$p_{SAT} = \left(\left(\hat{\beta}_{1j} + W_{it}\hat{\beta}_{5j} \right) + 2\left(\hat{\beta}_{2j} + W_{it}\hat{\beta}_{6j} \right) S_{it} + 3\left(\hat{\beta}_{3j} + W_{it}\hat{\beta}_{7j} \right) S_{it}^2 \right) P_{it} \cdot \tag{2}$$

The implicit price for saturated thickness is assumed to increase with property value, decrease with saturated thickness and vary across markets based on the shape of the hedonic price

[7] Domestic wells in the region draw from a deeper aquifers than the wells for irrigation. Our focus is the value of groundwater for irrigation.

function represented by coefficient estimates in Equation (2). Saturated thickness affects agricultural land values more for parcels near a well since buyers will consider groundwater conditions more carefully when a well indicates the prior use of a groundwater source. The second stage analysis only uses the implicit prices associated with agricultural parcels that have a well on the property.

The demand function for saturated thickness with the implicit prices in (2) for the dependent variable is

$$\begin{aligned} p_{SAT} = {} & \alpha_0 + \alpha_1 \text{SATTHICK} + \alpha_2 \text{LMKT1} + \alpha_3 \text{LMKT2} + \alpha_4 \text{LMKT3} + \\ & + \alpha_5 \text{AWS} + \alpha_6 \text{PRECIP} + \alpha_7 \text{ACRES} + \alpha_8 \text{INC} + \alpha_9 \text{INC\_NA} + \\ & + \alpha_{10} \text{EDU} + \alpha_{11} \text{PEER\_FM} + \alpha_{12} \text{PEER\_AWD} + \alpha_{13} \text{PEER\_TWR} + \mu \end{aligned} . \quad (3)$$

SATTHICK is the saturated thickness estimate associated with each survey respondent's farm, and LMKT1, LMKT2, LMKT3 are land market dummies corresponding to one of the regions in Figure 3. AWS and PRECIP are measures of soil water storage and recent rainfall on the farm. A negative (positive) coefficient on PEER_FM (α_6) implies that producers who receive greater rainfall decrease (increase) the shadow price of groundwater, and the groundwater and rainfall are substitutes (complements). ACRES is the acres of cultivated land on the farm; INC and INC_NA represent the household income and a dummy if income not reported; EDU is an index for the years of education attained; μ is an error term, and the vector α are preference parameters to estimate. PEER_FM, PEER_AWD, and PEER_TWR are dummies that indicate whether in the last ten years the farm operator had family or friends (i.e. peers) who use flow meters, alternate wetting and drying, and tail-water recovery, respectively.

We develop two set of instruments, one set based on the literature of residential sorting (Epple and Sieg 1999; Klaiber and Kuminoff, 2014) and the second set based on land market/demand shifter interaction terms (Bartik 1987; Kuminoff and Pope 2012). The sorting instrument SI is an index for the average level of saturated thickness in a county, which takes a value of one in the county with lowest saturated thickness, a value of two in the county with the second lowest saturated thickness, and so forth. A second sorting instrument is the interaction of SI and PEER_TWR. The other set of instruments are the land market dummies (LMKT2 and LMKT3) interacted with the percentage of farmland in cotton, which is valid under the assumption that the hedonic function varies across land market but unobserved tastes do not. The percentage of farmland in cotton proxies as a natural recharge demand shifter in LMKT2 and LMKT3 because cotton is principally grown in a region with more natural recharge, geographically East of Crowley's ridge and west of the Mississippi River (Figure 2). West of Crowley's ridge, but in LMKT2 and LMKT3, cotton and natural recharge are much lower.

5. Results and Discussion

The results for our hedonic analysis in Table 3 include coefficient estimates for saturated thickness variables that reveal the marginal effect for an acre-foot increase in saturated thickness. Our indicator for an irrigated parcel is the presence of a well on-property. We interact saturated thickness and the square and cube of saturated thickness with a dummy for a well on a parcel to examine how groundwater abundance affects the value of irrigated properties. The hedonic models from left to right in Table 3 indicate progressively more controls for time-invariant heterogeneity. The far left hedonic model has no spatial controls; the second column from the left has spatial controls for 23 counties in the study area, and the third column has the estimates for a hedonic model using spatial controls for 235 county subdivisions defined by the US Census Bureau. The far right hedonic model uses the county subdivisions controls but only consider parcel that produced rice in the last five years. The parcels producing rice cultivated on a flooded field presumably rely more on irrigation.

The hedonic model without spatial controls indicates there is no statistically significant effect of saturated thickness on the value of a parcel without a well. The coefficients on the saturated thickness variables interacted with well on parcel are significant. A similar pattern occurs for the hedonic models with county level spatial controls and county subdivision fixed effects. The statistical significance of the coefficients for saturated thickness on parcels with a well is strongest with county subdivision fixed effects, indicating a correlation of land values and saturated thickness with the unobserved spatial heterogeneity. At the bottom of Table 3 are the average marginal effects for saturated thickness for parcels with a well on the parcel, and these are significant for the specifications with county subdivision fixed effects. The estimate of the average marginal effect for the capitalized land value of additional water in-storage of all parcels with a well is a statistically significant \$8.96/ft when the saturated thickness is 80 feet. Finally, when considering the hedonic model for parcels that cultivated rice in the last five years, the average marginal effect of saturated thickness when the saturated thickness is 80 feet is slightly higher at \$9.07/ft. However, the average marginal effect is not statistically significant different from zero in all the hedonic models when the saturated thickness increases to 110 feet.

Other variables in the hedonic model, though not our main interest, have significant coefficients. Very acidic soils (pH less than 5.3) can harm crops, although rice prefers slightly acidic soil, and this lowers the land values. The coefficient on the acidic soil dummy is significant in the model with all parcels but not significant in the model with only rice parcels. An average increase in degree days between 10 and 32 Celsius over the past five years increases land value for the hedonic model with only rice parcels. An increase in commute time to a city with more than

40,000 people lowers the agricultural land value but greater commute time to a city with more than 5,000 people does not. The negative and significant coefficients on the dummies for the well on parcel and the well within a quarter mile indicate that potential buyers view a nearby well as evidence that the groundwater beneath the land is depleted and therefore less valuable.

Several variables, not significant on their own, are significant when interacted with the dummy for well on a parcel. Parcels with a well sold for more if the precipitation in the previous year was higher because buyers could have a lower cost of irrigation over the growing season. Also, parcels with a well and greater hydraulic conductivity have higher agricultural land value since local depressions in the aquifer created by a well refill faster. An on-farm reservoir within a half mile of a parcel with a well increases the value of the parcel, but a reservoir does not increase the value of a parcel without a well.

First stage hedonic estimates for saturated thickness ($\beta_{1j}, \beta_{2j}, \beta_{3j}, \beta_{5j}, \beta_{6j}, \beta_{7j}$), average land price per acre, and average saturated thickness are in Table 4 for each land market. Of the 24 first stage hedonic estimates, two in LMKT1 and three in LMKT3 are statistically significant (robust standard errors cluster at the county) on saturated thickness without the interaction of the well on property dummy, and three in LMKT3 only are statistically significant on the interaction variable of saturated thickness and the well on property dummy. The implicit price of saturated thickness if the well is on the parcel, evaluated at the average agricultural land price, is only statistically significant in LMKT1 ($78.37 per foot) and LMKT3 ($23.25 per foot) and for 80 feet of saturated thickness. Our implicit price for the entire study area ($8.91 per foot) falls within the range of implicit prices for the Ogalalla aquifer, less than $18 per foot (Sampson et al. 2019), even though the implicit price by land market is higher.

We test the sensitivity of the first stage results with alternative specifications for saturated thickness and different spatial thresholds of well dummies interacted with saturated thickness. The use of a natural log form for saturated thickness results in a lower implicit price than the cubic form for saturated thickness (see Table A2), and implicit price is not statistically significant in the hedonic model for all parcels. The preferred baseline cubic form is less restrictive on the curvature of the relationship between saturated thickness and property value. We define irrigated parcels, or properties expected to be influenced by a change in saturated thickness, as those with a well on the property. The spatial extent of saturated thickness capitalization could stretch farther however, and we test the assumption by extending the spatial threshold of well proximity to the property to a quarter mile and a half mile (see Table A2). The implicit price at a saturated thickness of 80 feet for the hedonic model using all parcels is higher when using a quarter mile dummy ($10.26 per foot) than an on property dummy ($8.91 per foot) but declines with the half mile dummy ($3.13 per foot). The value of parcels near a well rather than parcels with a well only on the property are responsive to saturated thickness change but this diminishes if the well is a half mile or farther away. We choose the well on property dummy because this avoids potential attenuation bias, and is most consistent with the hedonic modeling approach taken in states where the water right is tied to the land (Sampson et al. 2019).

Our last sensitivity test of the first stage results is a parcel fixed effects specification, but caution is warranted because the repeat sales sample is much smaller (1,172 observations) than the full sample (4,701). A two-sided *t*-test reveals statistically significant differences in the explanatory variable averages across the two samples (see Table A3). With parcel fixed effects, the implicit price at a saturated thickness of 80 feet is a statistically insignificant $22.4 per foot (Table A4), more than double the implicit price with only county subdivision fixed effects ($8.96 per foot).

Despite concerns about the smaller sample, this is evidence, similar to Sampson et al. (2019) for the Ogallala aquifer and Buck et al. (2014) for California surface water deliveries, that ignoring unobserved heterogeneity at the parcel level results in a downward bias of the in-situ value.

5.1 Second stage results

The implicit prices from equation (2) are the dependent variable in equation (3) for the estimation of the saturated thickness demand parameters. We estimate demand slope estimates for the survey sample using the implicit prices from the agricultural land transactions from the four land markets in the study area (Table 5). We assign a value of zero to observations with a negative implicit price in the baseline model for the second stage (Netusil et al. 2010; Day et al. 2007), and use sensitivity analysis with unadjusted prices to assess the impact of that choice in Table A6. Estimation of IV Model 1 and IV Model 2 is through a two-step instrumental variable (IV) generalized method of moments (GMM) estimator[8] with saturated thickness sorting indices (SI and SI*PEER_TWR) used for instrumental variables in IV Model 1 and additional demand shifter IVs (LMKT2_PCTCOT and LMKT3_PCTCOT) used in IV Model 2. Each IV Model shows the estimation results using the implicit prices from the first stage using all parcels (All farms) and using only the rice parcels (Rice farms[9]).

The negative coefficient on SATTHICK across all models indicates that landowners' WTP for saturated thickness decreases as aquifer conditions improve. Instrumenting for the endogenous quantity variable with the sorting instruments indicates the slope of the demand function is either

[8] The two stage least squares (2SLS) IV estimates of the standard errors are inconsistent in the presence of heteroscedasticity of an unknown form, which prevents valid inference. GMM is the usual approach taken to address the heteroscedasticity problem (Hansen 1982). Estimation of the model using two stage least squares provides qualitatively similar results.

[9] Some of the survey respondents in the rice farm models did not report cultivating rice in the previous year but did report cultivating rice in years before that.

-0.178 or more negative, given the positive bias expected even in IV estimation (Nevo and Rosen 2012). The strength of IVs should be evaluated since coefficients even more biased than OLS are possible with weak IVs (Stock et al. 2002). The first stage F-statistic is greater than 199 for IV Model 1 and greater than 716 for IV Model 2, with the full set of first stage regression results in Table A5. Another concern is that the IVs are correlated with the error term, and a test for this through overidentifying restrictions is possible when the number of IVs exceeds the number of endogenous variables. The Hansen J statistic for GMM estimation is not significant in any model, suggesting that correlation of the IVs with the error term is not present.

Given the positive bias expected in the slope coefficient, the own price elasticity of demand for in-situ groundwater (in absolute value terms) is no lower than 0.773 for all farms. Our elasticity is higher than those recently estimated in the groundwater demand literature (e.g. elasticities for annual pumping in the range of 0.46 to 0.55 (Bruno and Jessoe 2021; Hrozencik et al. 2021; Mieno and Brozovic 2017). The use of in-situ groundwater is possible over several years or longer, and the longer time frame within which to use groundwater increases the elasticity. Another factor contributing to the higher elasticity is substitutes through the storage of surface water abundant in the Arkansas winter season with reservoirs and tail-water recovery systems (Tran and Kovacs 2021).

Several of the covariates in equation (3) are statistically significant, providing evidence that farmers living in areas with higher available water storage in the soil are willing to pay more for saturated thickness. Farmers living in areas with higher average precipitation in the previous three years have weaker preferences for saturated thickness. These coefficient signs match expectations as farmers have a preferences for soil where water can effectively reach crops and where the crop water needs can be met with precipitation rather than costly irrigation inputs.

Having a peer who uses alternate wetting and drying for rice irrigation (PEER_AWD) lowers the WTP for saturated thickness in IV Models 1 and 2. Belonging to a peer network associated with a relatively new efficient irrigation practice for rice in Arkansas is a type of social capital that is a substitute for groundwater. However, the coefficients on PEER_FM and PEER_TWR are positive, although only statistically significant in IV model 2. Having a peer that uses an older irrigation practice related to monitoring groundwater use (i.e. flow meters) or using groundwater conjunctively with surface water (i.e. tail-water recovery system) are social capital types that complement groundwater. Some peer networks lead to decision-making that deemphasize natural capital and result in substitution with produced/human capital (i.e. alternative wetting and drying) while other peer networks build complementarities between natural capital and produced/human capital (i.e. flow meters and tail-water recovery systems).

5.2 Welfare implications

The welfare implications of a twenty foot decrease in saturated thickness, measured through greater per acre property value, are shown for initial saturated thicknesses of 40 feet to 180 feet (Table 6). A 20 foot decline in saturated thickness occurs over a period of about thirty years in the overdraft regions of Eastern Arkansas (ADA 2021; ASWCC 2005). The average landowner in all land markets, land market 1, and land market 3 has a saturated thickness of 120 feet, 60 feet, and 160 feet, respectively. In all land markets, a decrease in saturated thickness from 120 feet to 100 feet would decrease the per acre property value by $148 for all farms and $296 for rice farms. Landowners living in LMKT1, who experience a decrease in saturated thickness from 60 feet to 40 feet, are predicted to have the largest decrease in per acre property value, $317 for all farms and $963 for rice farms. The decrease in per acre property value for LMKT3 associated with a decrease in saturated thickness from 160 feet to 140 feet is $174 for all farms and $154 for rice farms.

The predicted change in the value per acre for all farms and rice farms associated with saturated thickness indicate that groundwater influences property values more for rice farms than all farms (Figure 4). The property value response to saturated thickness plateaus at around 130 feet of saturated thickness for all farms but continues to rise for rice farms until at least 160 feet of saturated thickness. A spatial prediction of the change in the property value per acre for a non-marginal increase (10 feet) in saturated thickness indicates that property value increases the most in LMKT1 and in LMKT3 to the West of Crowley's ridge (Figure 5).

6. Conclusion

Empirical measurement of the substitutability between the in-situ value of groundwater and climate indicators is a challenge because in-situ groundwater is a non-market good. One approach available to the practitioner is the second-stage hedonic analysis to estimate an inverse demand for natural capital. Shifters of the demand equation include measures of precipitation and available water storage because those influence people's management of their natural resources. Our empirical analysis of groundwater in the Arkansas Delta provides evidence for substitution between groundwater and the level of precipitation affected by climate change. Groundwater overdraft is a chronic challenge for agricultural and urban communities alike as populations increase, agriculture intensifies, and the climate changes. Proper groundwater management requires comparing private benefits to agricultural producers versus the conservation of natural resources.

Policy interventions are often created with the aim of increasing groundwater as illustrated by the recent development of California's Sustainable Groundwater Management Act (Kiparsky et al. 2017). However, estimation of a non-marginal change in the value of groundwater through the use a groundwater demand curve is a challenge since landowners choose how much groundwater to purchase and the price paid for the groundwater simultaneously. We contribute to the hedonic literature on groundwater using a two decade of panel dataset of agricultural land sales to determine the welfare implications associated with a non-marginal increase in saturated thickness. The own price elasticity of demand for in-situ groundwater is 0.773, which is larger than the elasticities estimated for the extractive value of groundwater, and we suspect this is because the in situ groundwater value is based on use over many years while the extractive groundwater value is confined to a single growing season. Assuming rainfall remains the same, we predict that farm landowners in Arkansas lose $148 to $281 in property value per acre with twenty foot decline over thirty years in the saturated thickness. Those losses will magnify if the climate become drier.

Central to the climate debate are questions around the limits to substitutability between groundwater and climate resources, and properly measured shadow prices of natural capital are needed to address those questions. The shadow prices from Eq. 3 are affected by demand shifters that include precipitation, and the substitution or complementarity emerges from the underlying preferences and management decisions of people in their environment. Our application to groundwater shows that precipitation can have a vital role in systems with interacting natural capital stocks. Our approach could be extended to include a greater array of climate measures (e.g. growing degree days, heat stress) and natural capital (e.g. water and soil quality). Policy makers and natural resource managers may use the empirically measured relationship among the groundwater and climatic indicators to assess tradeoffs with scarce budgets.

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Table 1. Variable summary statistics for the first stage hedonic equation

Variable	Well on parcel				No well on parcel			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Price per acre ($/acre)	3,146.5	2165.2	203.5	17,490.7	2,689.9	2,473.1	201.2	19,954.6
Parcel larger than 100 acres (Binary)	0.3	0.5	0	1	0.1	0.4	0	1
Well within quarter mile (Binary)	--	0.5	0.5	0	1			
Well within half mile (Binary)	--	0.9	0.2	0	1			
Saturated thickness (ft)	119.5	57.8	0.33	269.9	119.1	54.1	0	324.7
Hydraulic Conductivity (ft/day)	141.1	92.4	5	370.39	142.0	94.7	3	369.2
Intermittent stream within quarter mile (Binary)	0.6	0.5	0	1	0.6	0.5	0	1
Reservoir within half mile (Binary)	0.01	0.1	0	1	0.01	0.1	0	1
Root zone available water storage (inches)	10.2	1.6	0.1	22.1	10.3	1.7	0	24.9
Soil organic matter (kg per square meter)	1.50	0.4	0.03	3.96	1.49	0.4	0	3.85
Acidic soils (percent of land pH<5.3)	3.1	12.5	0	98.6	3.5	13.6	0	100
Growing season precipitation: previous year (inches)	25.5	7.1	10.9	62.9	23.9	6.9	11.5	75.6
Growing season precipitation: three year average (inches)	24.8	4.7	15.0	59.9	23.7	4.9	14.6	65.2
Degree days between 10 and 32 Celsius: five year average (degrees^{c}days)	2,501.4	314.4	2,102.2	5,905.8	2,493.7	346.1	2,068.2	7,999.8
Degree days over 32 Celsius: five year average (degrees^{c}days)	0.3	0.5	0	3.4	0.2	0.4	0	3.7
Commute time to 5,000 population (minutes)	26.3	11.7	3.8	76.3	27.2	12.6	2.9	73.9
Commute time to 40,000 population (minutes)	50.1	25.5	7.1	157.8	54.6	29.5	4.7	162.6

Note: Number of parcels with a well on the property is 890, and the number of parcels without a well on the property is 3,811.

Table 2. Definitions and summary statistics of the farm operation characteristics for the second stage groundwater inverse demand equation

Variable	Definition	Sample Mean	Sample standard deviation	2017 Census of Agriculture Mean
SATTHICK	Saturated thickness (feet)	84.01	38.25	
Demand shifters				
LMKT1	=1 if respondent live in the land market one^	0.14	0.35	
LMKT2	=1 if respondent live in the land market two	0.39	0.49	
LMKT3	=1 if respondent live in the land market three	0.16	0.36	
AWS	Available water storage for the top five feet of soil (inches)	23.07	3.05	
PRECIP	Growing season (April to October) precipitation: three year average (inches)	27.30	2.34	
ACRES	Acres irrigated	2,308	2,716	1459.1
INC	Household income in 2015 from all sources ($ thousands)	104.9	105.5	152.2
INC_NA	=1 if household income not reported	0.23	0.42	
EDU	=1 if no formal education and =8 if beyond Master's degree	4.95	1.55	
PEER_FM	=1 if peer used flow meters in past 10 years	0.62	0.49	
PEER_AWD	=1 if peer used alternate wetting and drying for rice irrigation in past 10 years	0.33	0.47	
PEER_TWR	=1 if peer used a tail-water recovery system in past 10 years	0.66	0.47	
Excluded instruments				
SI	Index of the average saturated thickness for a county. =1 for the lowest saturated thickness, =2 for the next lowest saturated thickness, and so forth.	12.31	6.99	
SI*PEER_TWR	Interaction term of SI and PEER_TWR	7.49	7.71	
LMKT2_PCTCOT	LMKT2*Percentage of irrigated cropland in cotton	1.27	7.77	
LMKT3_PCTCOT	LMKT3*Percentage of irrigated cropland in cotton	0.86	7.58	

Note: GMM Instruments include all the demand shifters and excluded instruments. ^ Figure 4 shows the land markets. ^^ Peers include a close family, friend, or neighbor who is an agricultural producer.

Table 3. Coefficient estimates for the first stage hedonic model

	No spatial fixed effects	County spatial fixed effect	County subdivision fixed effects	County subdivision fixed effects: Rice^
Saturated thickness	-6.06E-03	-4.13E-03	2.99E-03	5.92E-03
	(5.63E-03)	(5.89E-03)	(8.25E-03)	(6.67E-03)
Square of saturated thickness	3.47E-05	2.68E-05	-2.16E-05	-4.65E-05
	(4.33E-05)	(4.37E-05)	(6.11E-05)	(4.79E-05)
Cube of saturated thickness	-4.73E-08	-4.45E-08	4.38E-08	9.91E-08
	(9.98E-08)	(9.83E-08)	(1.34E-07)	(1.04E-07)
Well on parcel interacted with saturated thickness	0.013[b]	0.0138[c]	0.023[b]	0.022[a]
	(0.006)	(0.007)	(0.009)	(0.008)
Well on parcel interacted with square of saturated thickness	-9.58E-05[c]	-9.74E-05[c]	-1.72E-04[b]	-1.62E-04[a]
	(5.07E-05)	(5.90E-05)	(6.89E-05)	(5.75E-05)
Well on parcel interacted with cube of saturated thickness	2.13E-07[c]	2.11E-07	3.82E-07[b]	3.75E-07[a]
	(1.22E-07)	(1.40E-07)	(1.57E-07)	(1.27E-07)
Hydraulic Conductivity	1.20E-04	1.11E-04	1.83E-04	3.62E-04
	(3.18E-04)	(3.29E-04)	(6.12E-04)	(6.26E-04)
Root zone available water storage	0.019	0.013	0.012	-0.001
	(0.013)	(0.013)	(0.010)	(0.014)
Soil organic matter	0.009	0.047	0.0532	0.013
	(0.049)	(0.054)	(0.047)	(0.061)
Acidic soils	1.16E-04	-5.52E-04	-1.89E-03[c]	-1.30E-03
	(7.94E-04)	(9.37E-04)	(1.04E-03)	(1.80E-03)
Growing season precipitation: previous year	1.24E-03	1.64E-03	3.84E-03	-1.38E-03
	(6.09E-03)	(6.16E-03)	(6.49E-03)	(7.39E-03)
Degree days between 10 and 32 Celsius: five year average	1.08E-04	1.05E-04	1.17E-04	2.53E-04[c]
	(8.00E-05)	(1.30E-04)	(1.17E-04)	(1.31E-04)
Degree days over 32 Celsius: five year average	-0.038	-0.03	-0.041	0.011
	(0.038)	(0.046)	(0.044)	(0.045)
Commute time to 5,000 population	-8.67E-04	-2.73E-03	-1.59E-03	4.95E-03
	(2.78E-03)	(3.88E-03)	(7.35E-03)	(5.41E-03)
Commute time to 40,000	-0.005[a]	-0.007[b]	-0.0129[a]	-0.016[a]

population				
	(0.001)	(0.003)	(0.003)	(0.004)
Well on parcel	-0.715[a]	-0.747[a]	-0.972[a]	-1.142[a]
	(0.227)	(0.269)	(0.305)	(0.309)
Well within quarter mile	-0.101[b]	-0.115[b]	-0.133[a]	-0.104[c]
	(0.044)	(0.050)	(0.051)	(0.055)
Well within half mile	0.189[b]	0.201[b]	0.213	0.146
	(0.090)	(0.097)	(0.132)	(0.164)
Reservoir within half mile	0.057	0.038	0.021	0.019
	(0.199)	(0.180)	(0.110)	(0.156)
Intermittent stream within quarter mile	0.046	0.053	0.058	0.0349
	(0.041)	(0.048)	(0.048)	(0.0416)
Other variables interacted with well on parcel				
Growing season precipitation: previous year	6.26E-04[a]	5.94E-04[a]	7.35E-04[a]	5.74E-04[b]
	(1.91E-04)	(2.21E-04)	(2.62E-04)	(2.39E-04)
Hydraulic Conductivity	4.06E-04[c]	4.09E-04[c]	4.79E-04[c]	6.37E-04
	(2.20E-04)	(2.37E-04)	(2.91E-04)	(3.88E-04)
Reservoir within half mile	0.335[b]	0.325[c]	0.332[b]	0.335[b]
	(0.145)	(0.134)	(0.187)	(0.157)
Implicit price if well on parcel				
80 feet	1.47 (3.46)	4.58 (3.35)	8.96[b] (3.92)	9.07[b] (3.84)
110 feet (average)	-0.88 (2.38)	0.62 (2.23)	-3.28 (3.42)	-3.37 (2.99)
Spatial fixed effects (#)	0	23	235	235
BIC	85,498	85,400	84,879	75,614
Number of observations	4,701	4,701	4,701	4,202

Standard errors clustered at counties in parentheses. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$. ^ Rice parcels include any parcel with rice in the last five years.

Table 4. Implicit price for a one foot increase in saturated thickness by land market – All parcels

	LMKT1	LMKT2	LMKT3	LMKT4
Coefficient				
Saturated thickness	-0.019 (0.026)	0.006 (0.016)	0.018 (0.006)[a]	-0.035 (0.041)
Square	4E-04 (2E-04)[c]	-7E-05 (2E-04)	-1E-04 (4E-05)[a]	2E-04 (3E-04)
Cube	-2E-06 (5E-07)[a]	2.1E-07 (5E-07)	3E-07 (8E-08)[a]	-2E-07 (6E-07)
Well on parcel interacted with saturated thickness	-0.039 (0.072)	0.030 (0.038)	0.032 (0.007)[a]	0.084 (0.076)
Square	6.4E-04 (0.001)	-3E-04 (4E-04)	-2E-04 (6E-05)[a]	-7E-04 (7E-04)
Cube	-2E-06 (5E-06)	1.E-06 (1E-06)	5E-07 (1E-07)[a]	2E-06 (2E-06)
Land price per acre	2,863	2,520	3,165	2,315
Saturated thickness	61	106	159	99
Implicit price if well on parcel				
80 feet	78.37[c] (47.7)	-7.74 (6.01)	23.25[a] (3.39)	-30.24 (35.86)
111 feet	55.57 (60.7)	-11.26 (10.5)	-3.66 (5.99)	-44.34 (48.03)

Standard errors clustered at counties in parentheses. Land prices per acre are in 2019 dollars using the Case-Shiller National Home Price Index. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table 5. Coefficient estimates for GMM estimation of the second stage groundwater inverse demand equation

Variable	IV Model 1		IV Model 2	
	All farms	Rice farms	All farms	Rice farms
SATTHICK	-0.178[a] (0.039)	-0.166[a] (0.062)	-0.134[a] (0.029)	-0.120[a] (0.042)
LMKT1	20.2[a] (7.73)	57.6[a] (17.33)	14.29 (10.43)	48.44[b] (20.79)
LMKT2	19.21[a] (3.16)	24.32[a] (4.14)	18.45[a] (3.83)	24.82[a] (4.67)
LMKT3	22.33[a] (3.84)	21.54[a] (7.33)	20.51[a] (4.30)	19.99[a] (6.66)
AWS	1.78[a] (0.488)	3.05[a] (0.953)	1.75[a] (0.544)	2.86[a] (0.81)
PRECIP	-3.47[a] (0.629)	-4.03[a] (0.796)	-3.22[a] (0.633)	-3.99[a] (0.773)
ACRES	0.001 (0.0004)	0.0003 (0.001)	-0.0003 (0.001)	-0.0003 (0.001)
INC	0.004 (0.005)	0.004 (0.009)	0.008 (0.006)	0.009 (0.01)
INC_NA	-1.26 (3.03)	-4.88 (5.97)	0.636 (3.17)	-2.09 (5.32)
EDU	-1.57[a] (0.443)	-2.52[a] (0.84)	-1.99[a] (0.445)	-3.01[a] (0.687)
PEER_FM	2.41 (1.57)	3.54[c] (2.02)	3.05[c] (1.61)	4.29[b] (2.06)
PEER_AWD	-4.39[c] (2.42)	-8.42[c] (4.89)	-5.27[a] (1.78)	-9.18[a] (3.43)
PEER_TWR	1.11 (2.66)	1.764 (4.22)	3.98[b] (1.93)	5.62[b] (3.19)
Constant	68.62[a] (19.91)	57.59 (35.14)	59.73[a] (15.70)	57.34[b] (25.26)
Instruments	SI; SI*PEER_TWR		SI; SI*PEER_TWR; LMKT2_PCTCOT; LMKT3_PCTCOT	
Observations				
Second stage	182		182	
First stage	4,701		4,202	
R^2	0.37	0.40	0.39	0.41
Own price elasticity of demand	-0.773[a] (0.170)	-1.335[a] (0.088)	-1.030[a] (0.227)	-1.849[a] (0.66)
First stage F-statistic (p-value)	199.2[a] (0.00)		716.40[a] (0.00)	
Overidentification Hansen J (p-value)	0.46 (0.49)	0.12 (0.73)	2.76 (0.43)	2.12 (0.55)

Robust standard errors clustered at counties in parentheses. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$. The negative implicit prices from the first stage are adjusted to zero. The results for all farms when the negative implicit prices are not adjusted to zero are in Table A4. IV estimation for rice farmers use the implicit prices from a first stage specification with township fixed effects and rice parcels.

Table 6. Per acre property value benefit from changes in saturated thickness using second stage welfare measures

Change in saturated thickness (feet)	All farms			Rice farms		
	All land markets	LMKT1	LMKT3	All land markets	LMKT1	LMKT3
20 to 40	362 ± 304	370 ± 429	494 ± 306	488 ± 592	1011 ± 871	442 ± 589
40 to 60	308 ± 292	317 ± 417	441 ± 294	440 ± 575	963 ± 854	394 ± 572
60 to 80	255 ± 281	263 ± 405	388 ± 282	392 ± 558	915 ± 838	346 ± 555
80 to 100	201 ± 269	210 ± 393	334 ± 271	344 ± 541	867 ± 820	298 ± 538
100 to 120	148 ± 257	156 ± 382	281 ± 259	296 ± 524	819 ± 804	250 ± 521
120 to 140	94 ± 245	103 ± 370	227 ± 247	248 ± 507	771 ± 787	202 ± 504
140 to 160	41 ± 233	49 ± 358	174 ± 235	200 ± 490	723 ± 770	154 ± 487
160 to 180	--	--	120 ± 224	152 ± 473	675 ± 753	106 ± 470

95% confidence intervals shown beside each estimate of the per acre property value benefit. The first stage is the quadratic specification for saturated thickness and township fixed effects while the second stage is the linear specification for inverse groundwater demand. Rice farmers include survey respondents who produce rice, and the implicit prices come from a first stage specification with township fixed effects and rice parcels.

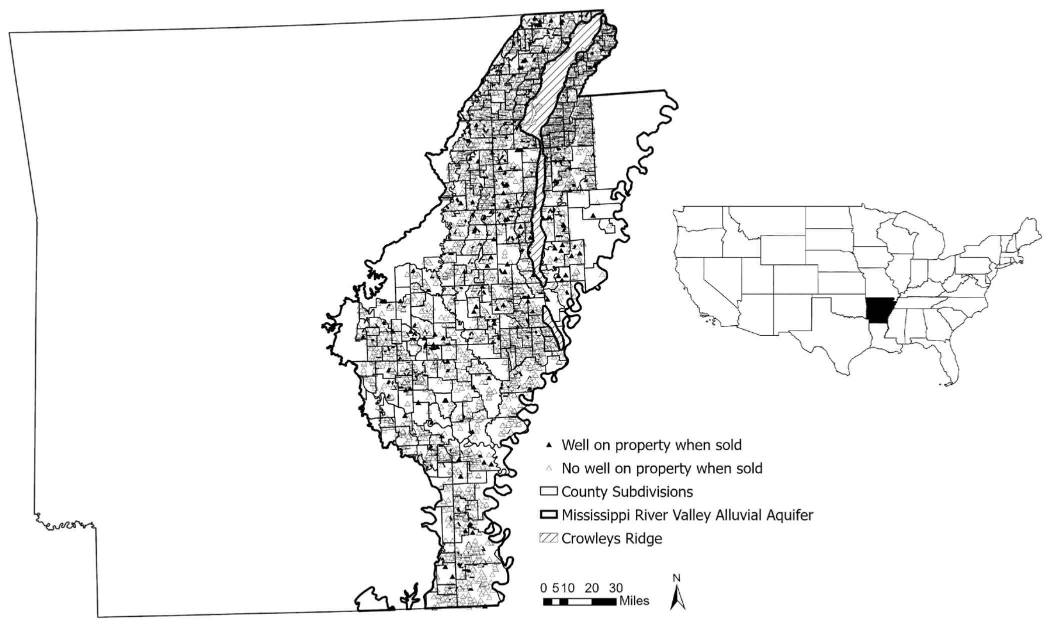

Figure 1. Location of parcels with and without a well when sold and the county subdivision boundaries.

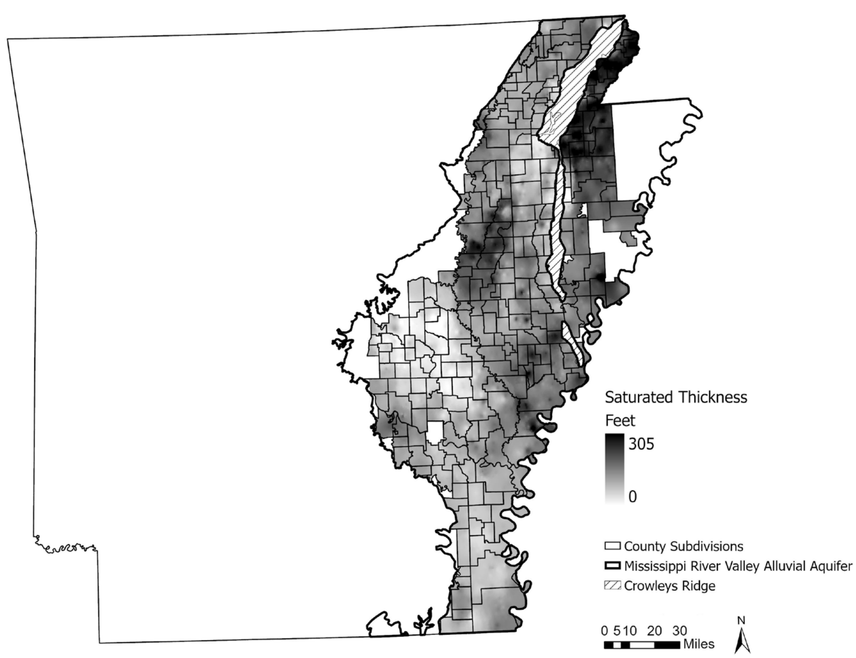

Figure 2. The saturated thickness in 2010 for the Mississippi Valley Alluvial Aquifer

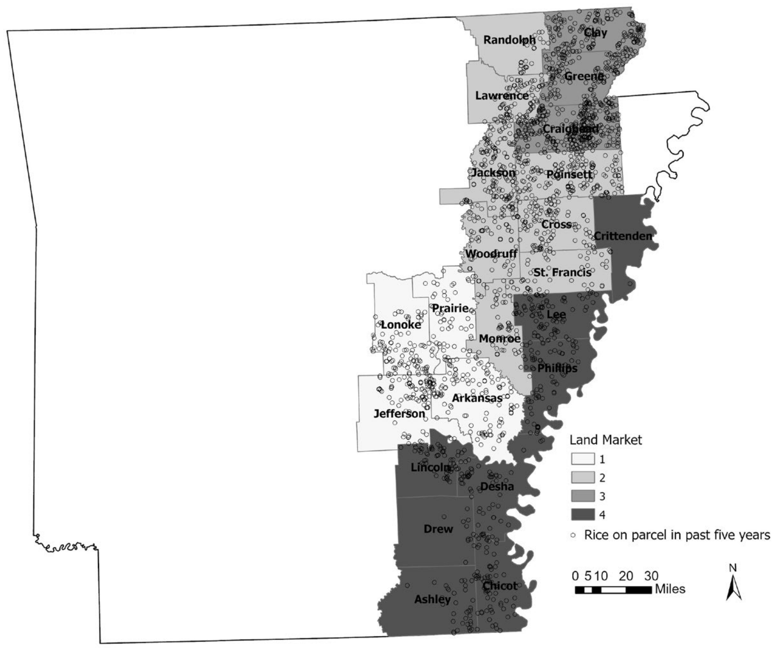

Figure 3. Land markets and the location of parcels with any rice in the five years prior to sale

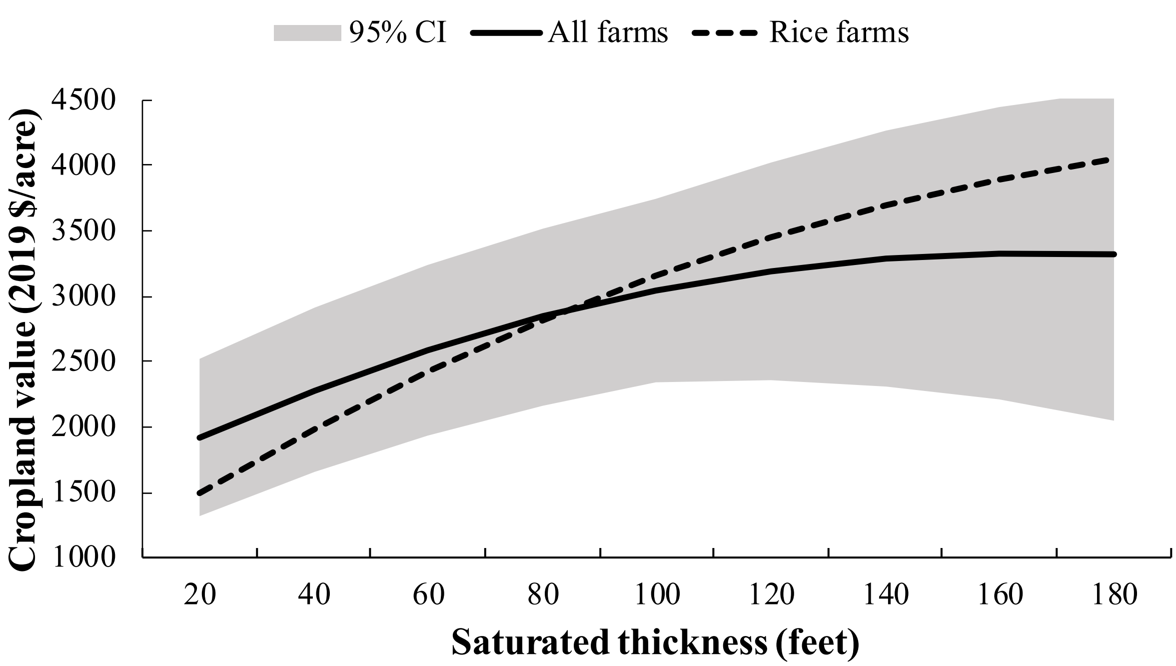

Figure 4. The predicted increase in the value per acre for an average parcel and an average rice parcel associated with saturated thickness based on the inverse demand equation for groundwater.

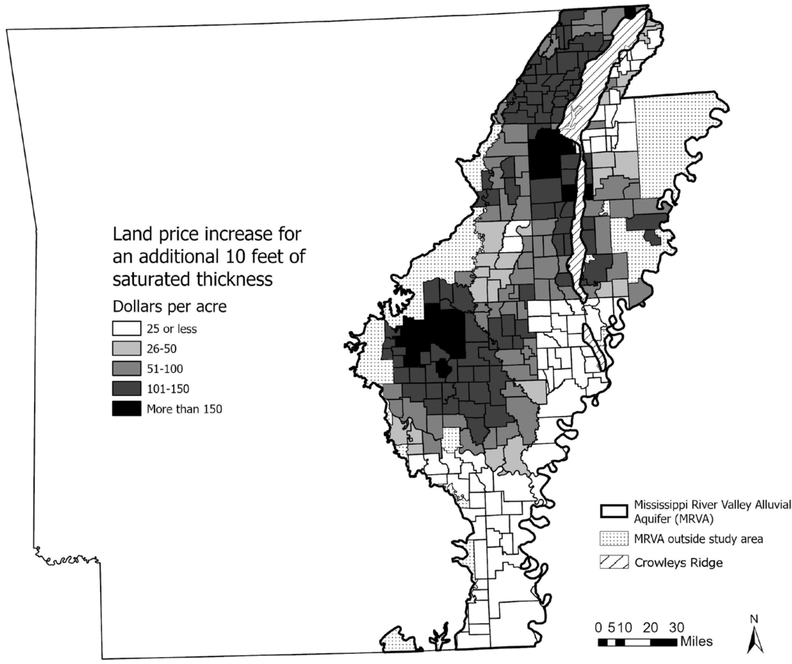

Figure 5. Spatial prediction of the average change in the value per acre of agricultural land associated with a 10 foot increase in saturated thickness based on the inverse demand equation for groundwater.

Appendix

Tables A1 has the coefficient estimates for predicting the saturated thickness from the first-stage data to then determine the saturated thickness for each of the survey responses. Table A2 has the coefficient estimates for the first-stage hedonic model using the natural log of saturated thickness, rather than the cubic specification, and by well proximity (i.e. quarter and half mile rather than on property). Table A3 has the mean difference *t*-tests for repeat sale parcels and all parcels. Table A4 has the coefficient estimates for the hedonic model of the parcels with repeat sales. Table A5 has the implicit prices for the rice parcels by land submarket associated with a one foot increase in saturated thickness. Table A6 has the instrumental variable first-stage regression results. Table A7 has the coefficient estimates for alternative second stage groundwater demand equations based on unadjusted implicit prices or OLS estimation. Figure A1 shows the difference in saturated thickness between the three year moving average for 1999 and the three year moving average for 2019.

Table A1. Estimation of the saturated thickness using the first stage data for the prediction of saturated thickness on the farms corresponding to the survey responses

Variable	Coefficient	Robust standard error
County dummies		
Ashley	-9.91	(6.63)
Chicot	-15.92[a]	(5.06)
Clay	24.46[a]	(5.69)
Craighead	35.03[a]	(5.41)
Crittenden	-24.08	(17.53)
Cross	15.00[a]	(4.92)
Desha	-13.66[b]	(5.37)
Drew	-13.63	(10.70)
Greene	25.22[a]	(5.83)
Jackson	37.57[a]	(4.52)
Jefferson	-3.96	(5.17)
Lawrence	20.57[a]	(5.06)
Lee	31.81[a]	(4.86)
Lincoln	-13.62[b]	(5.61)
Lonoke	-37.18[a]	(5.10)
Monroe	20.79[a]	(5.99)
Phillips	49.32[a]	(4.96)
Poinsett	5.44	(4.99)
Prairie	-23.82[a]	(5.95)
Randolph	20.46[a]	(7.65)
St. Francis	20.42[a]	(5.95)
Woodruff	65.45[a]	(5.15)
East of Crowley's Ridge	43.51[a]	(3.59)
Percent corn in last five years	0.26[a]	(0.073)
Percent cotton in last five years	0.51[a]	(0.041)
Percent rice last in five years	-0.39[a]	(0.039)
Percent soybeans in last five years	0.096[a]	(0.037)
Reservoir within half mile	-20.06[a]	(6.31)
Constant	76.62[a]	(4.18)

Dependent variable is saturated thickness from the first stage. Standard errors clustered at counties in parentheses. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$. Number of observations is 2,905. R-squared is 0.56. The explanatory variables for the prediction of saturated thickness in the first stage are also available and collected independently in the irrigation survey.

Table A2. Coefficient estimates for the hedonic model with the natural log of saturated thickness and by well proximity

	Natural log specification		Well proximity	
	All parcels	Rice parcels	Quarter mile	Half mile
Natural log of saturated thickness	0.022	0.027	--	--
	(0.093)	(0.08)	--	--
Well on parcel interacted with natural log of saturated thickness	0.075	0.155[b]	--	--
	(0.082)	(0.082)	--	--
Saturated thickness	--	--	-0.00714	-0.0015
	--	--	(0.007)	(0.022)
Square of saturated thickness	--	--	3.43E-05	-4.6E-05
	--	--	(4.96E-05)	(0.0002)
Cube of saturated thickness	--	--	-4.07E-08	2.38E-07
	--	--	(1.15E-07)	(4.94E-07)
Well proximity dummy interacted with saturated thickness	--	--	0.028567[a]	0.010461
	--	--	(0.009)	(0.0246)
Well proximity dummy interacted with square of saturated thickness	--	--	-0.00018[a]	-2E-05
	--	--	(6.54E-05)	(0.0002)
Well proximity dummy interacted with cube of saturated thickness	--	--	3.39E-07[b]	-9.74E-08
	--	--	(1.42E-07)	(5.22E-07)
Implicit price if well on parcel				
80 feet	3.34 (2.43)	6.31[a] (2.01)	10.26[a] (3.51)	3.13 (3.69)
111 feet (average)	2.41 (1.75)	4.55[a] (1.45)	-0.26 (2.13)	-1.26 (2.47)

Standard errors clustered at counties in parentheses. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table A3. Mean difference *t*-test for repeat sale parcels and all parcels as well as summary statistics for repeat sale parcels

Variable	Two-sided *t*-test^	Well on parcel				No well on parcel			
	p-value	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Price per acre ($/acre)	0.15	3,105.9	2,054.6	237.1	17,490.7	2,568.8	2,157.5	203.5	19,675.9
Saturated thickness (ft)	0.04	122.7	57.4	6.1	250.0	121.9	59.6	2.5	324.7
Hydraulic conductivity (ft/day)	0.20	145.7	96.5	6.0	357.9	136.8	95.1	5.0	362.4
Root zone available water storage (inches)	0.00	10.3	1.9	1.3	22.1	10.6	2.3	5.6	24.9
Soil organic matter (kg per square meter)	0.00	1.5	0.4	0.1	3.4	1.5	0.4	1.0	3.9
Acidic soils (percent of land pH<5.3)	0.38	2.8	12.0	0.0	87.7	3.3	12.1	0.0	100.0
Growing season precipitation: previous year (inches)	0.00	26.2	8.0	12.7	62.9	25.2	8.9	11.9	75.7
Growing season precipitation: three year average (inches)	0.00	25.5	5.9	15.7	59.9	25.0	7.3	14.9	65.2
Degree days between 10 and 32 Celsius: five year average (degrees*days)	0.00	2,561.5	522.8	2,102.2	5,905.8	2,598.0	638.5	2,110.3	7,999.8
Degree days over 32 Celsius: five year average (degrees*days)	0.08	0.3	0.5	0.0	3.4	0.2	0.4	0.0	3.4
Commute time to 5,000 population (minutes)	0.14	27.3	12.3	7.1	59.0	26.3	12.8	3.1	69.7
Commute time to 40,000 population (minutes)	0.00	50.1	23.7	7.1	117.9	51.1	28.4	7.1	140.7
Well within quarter mile (Binary)	0.01			--		0.5	0.5	0.0	1.0
Well within half mile (Binary)	0.09			--		1.0	0.2	0.0	1.0
Reservoir within half mile (Binary)	0.81	0.0	0.1	0.0	1.0	0.0	0.1	0.0	1.0
Intermittent stream within quarter mile (Binary)	0.66	0.6	0.5	0.0	1.0	0.6	0.5	0.0	1.0
Parcel larger than 100 acres (Binary)	0.30	0.3	0.5	0.0	1.0	0.1	0.3	0.0	1.0

Note: Number of repeat sales parcels with a well on the property is 261, and the number of repeat sales parcels without a well on the property is 911. ^The two-sided *t*-test has the null hypothesis that the difference in the mean of each variable across the repeat sale subsample and the full sample is zero. A *p*-value of 0.1 indicates a rejection of the null hypothesis with a type I error of 10%.

Table A4. Coefficient estimates for the hedonic model of parcels with repeat sales

	Township spatial fixed effects	Parcel spatial fixed effects
Saturated thickness	0.003409	-0.01055
	(0.008)	(0.019622)
Square of saturated thickness	-4.4E-05	0.000121
	(5.88E-05)	(0.000188)
Cube of saturated thickness	1.37E-07	-2.37E-07
	(1.38E-07)	(5.20E-07)
Well on parcel interacted with saturated thickness	0.0681[a]	0.032784
	(0.02)	(0.038739)
Well on parcel interacted with square of saturated thickness	-0.00054[a]	-0.00025
	(0.0001)	(0.0003)
Well on parcel interacted with cube of saturated thickness	1.24E-06[a]	5.91E-07
Implicit price if well on parcel		
80 feet	12.6 (12.6)	22.4 (18.5)
111 feet (average)	-19.92[a] (5.49)	17.4 (16.9)
Spatial controls	235	547
Number of observations	1,172	

Standard errors clustered at counties in parentheses. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table A5. Implicit price for a one foot increase in saturated thickness by land markets – rice parcels

	LMKT1	LMKT2	LMKT3	LMKT4
Coefficient				
Saturated thickness	0.027 (0.11)	0.017 (0.028)	0.021[b] (0.009)	-0.002 (0.03)
Square	6E-05 (0.001)	-2E-04 (3E-04)	-2E-04[a] (5E-05)	-2E-04 (3E-04)
Cube	-1E-06 (3E-06)	5E-07 (9E-07)	3E-07[a] (9E-08)	6E-07 (7E-07)
Well on parcel interacted with saturated thickness	-0.195 (0.57)	0.027 (0.062)	0.029[a] (0.009)	0.04 (0.11)
Square	0.003 (0.01)	-3E-04 (6E-04)	-2E-04[a] (6E-05)	-3E-04 (0.001)
Cube	-1E-05 (5E-05)	1E-06 (2E-06)	5E-07[a] (1E-07)	6E-07 (3E-06)
Land price per acre	2,884	2,502	3,011	2,199
Saturated thickness	61	105	156	98
Implicit price if well on parcel				
80 feet	201.1 (474.1)	-9.40 (7.04)	22.3[a] (5.86)	-29.5 (38.7)
111 feet	153.9 (200.9)	-14.73 (13.9)	-4.32 (5.07)	-45.8 (45.2)

Standard errors clustered at counties in parentheses. Land prices per acre are in 2019 dollars using the Case-Shiller National Home Price Index. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table A6. IV first-stage regression results

Variable	Dependent variable: SATTHICK	
	IV Model 1	IV Model 2
RBI	5.30[a] (0.45)	5.05[a] (0.46)
RBI*PEER_TWR	-1.06[b] (0.49)	-1.24[c] (0.72)
PCTCOT_LMKT2	--	1.09[a] (0.07)
PCTCOT_LMKT3	--	1.03[a] (0.04)
LMKT1	2.99 (5.47)	1.33 (5.21)
LMKT2	-2.57[b] (4.65)	-6.27[b] (2.54)
LMKT3	1.46 (6.62)	-2.39 (4.22)
AWS	0.48 (0.83)	-0.08 (0.48)
PRECIP	-1.14 (0.96)	-0.59 (0.67)
ACRES	0.001[c] (0.0006)	0.0005 (0.0006)
INC	0.03[b] (0.02)	0.01 (0.01)
INC_NA	5.36 (4.18)	2.41 (2.78)
EDU	0.48 (0.99)	0.2 (0.69)
PEER_FM	-0.16 (3.3)	-2.63 (2.28)
PEER_AWD	-2.03 (3.21)	-1.3 (2.37)
PEER_TWR	0.19 (7.81)	4.86 (7.38)
Constant	37.65[b] (35.01)	44.3[c] (21.94)
Observations	182	182

Robust standard errors clustered at counties in parentheses. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table A7. Coefficient estimates for the alternative second stage groundwater demand equations

Variable	Unadjusted implicit prices		OLS estimation with adjusted implicit prices	
	All farms	Rice farms	All farms	Rice farms
SATTHICK	-0.173[a] (0.04)	-0.137 (0.085)	-0.045 (0.096)	0.096 (0.194)
LMKT1	10.68 (24.93)	28.64 (47.43)	20.26 (12.00)	60.33[b] (27.06)
LMKT2	26.59[a] (6.05)	29.51[a] (7.67)	18.33[a] (5.09)	21.99[b] (9.68)
LMKT3	29.65[a] (6.81)	23.48[b] (11.95)	17.76[b] (6.41)	11.66 (13.56)
AWS	3.14[a] (0.765)	4.36[a] (1.39)	1.56[b] (0.634)	2.54[b] (1.21)
PRECIP	-2.88[a] (0.939)	-3.33[b] (1.33)	-3.39[a] (0.907)	-3.69[b] (1.74)
ACRES	-0.0003 (0.0003)	-0.001 (0.0004)	-0.001 (0.0004)	-0.0001 (0.001)
INC	0.019 (0.013)	0.027[c] (0.016)	0.002 (0.009)	-0.001 (0.017)
INC_NA	3.21 (5.13)	1.73 (8.78)	-1.54 (4.13)	-6.06 (9.31)
EDU	-4.08[a] (1.03)	-5.69[a] (1.07)	-2.24[a] (0.699)	-3.70[b] (1.34)
PEER_FM	4.99[b] (2.44)	7.54[b] (3.38)	0.954 (2.11)	0.416 (3.10)
PEER_AWD	-9.46[a] (2.96)	-16.37[a] (5.03)	-2.08 (2.61)	-4.39 (4.12)
PEER_TWR	13.84[a] (2.68)	20.76[a] (5.21)	4.61 (3.04)	9.59 (6.95)
Constant	6.49 (29.34)	-8.89 (48.55)	63.26[b] (27.38)	43.15 (54.09)
Instruments	SI; SI*PEER_TWR; LMKT2_PCTCOT; LMKT3_PCTCOT		--	
Observations				
Second stage	182			
First stage	4,701	4,202	4,701	4,202
R^2	0.26	0.09	0.42	0.44
Own price elasticity of demand	-0.798[a] (0.19)	-1.619 (1.00)	-3.08 (6.61)	2.32 (4.69)
Kleibergen-Paap Wald F-statistic (p-value)	716.40[a] (0.00)		--	
Overidentification Hansen J (p-value)	3.46[c] (0.33)	2.82[c] (0.42)	--	--

Robust standard errors clustered at counties in parentheses. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$. IV estimation for rice farmers use the implicit prices from a first stage specification with township fixed effects and rice parcels.

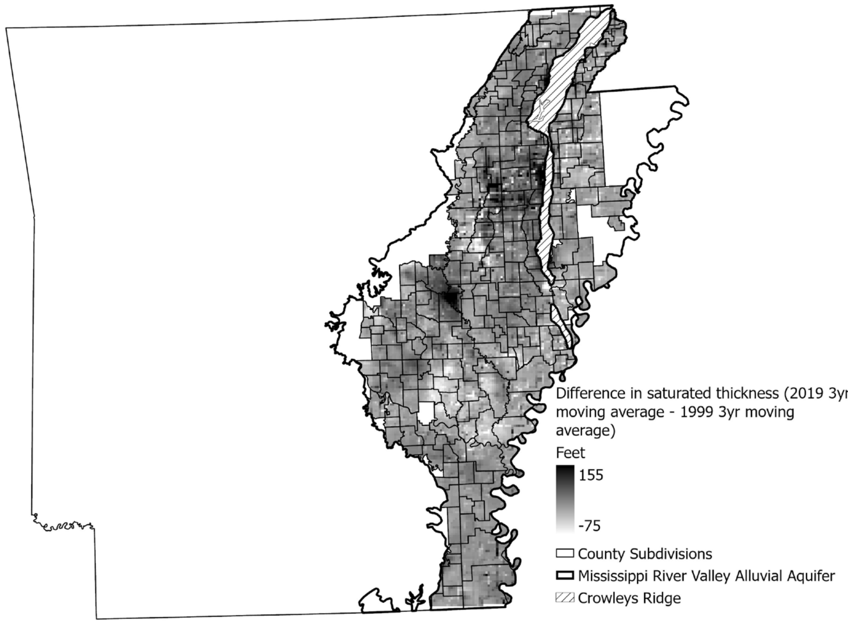

Figure A1. Change in saturated thickness between the three year moving average for 1999 and the three year moving average for 2019