Journal of Agricultural and Applied Economics (2023), **55**, 194–216
doi:10.1017/aae.2023.15

RESEARCH ARTICLE

Estimating the Demand for Groundwater: A Second-stage Hedonic Land Price Analysis for the Lower Mississippi River Alluvial Plain, Arkansas

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Abstract
We estimate the benefits of the saturated thickness (water-bearing porous material) of the alluvial aquifer in Arkansas through an application of the hedonic price model to the sale of agricultural land. There is evidence from the first-stage analysis of diminishing returns from increasing saturated thickness. Using a survey of farmer operators' preferences and socioeconomic characteristics, we recover the underlying demand function for saturated thickness in a second-stage analysis. Shifts in the demand function reveal that produced/social capital can be a substitute or a complement to saturated thickness, and human capital is a substitute for saturated thickness.

Keywords: demand estimation; natural resource wealth; weak sustainability

JEL classifications: Q25; Q24; Q51

1. Introduction

Groundwater is an essential input for nearly 40% of the global area in use by irrigated agriculture (Siebert et al., 2010). The owners of the land above an aquifer, who may operate the land themselves or may lease the land to operators, receive benefits from the groundwater for provisioning services. Landowners implicitly pay for the benefits of the aquifer by purchasing land that is more expensive than similar land with less groundwater. Other in situ values of groundwater include ecological, buffer, subsidence avoidance, recreational, sea water intrusion avoidance, and nonuse (NRC 1997). The Mississippi River Valley Alluvial Aquifer (MRVA) is the primary irrigation source for the Mississippi River Delta agricultural region. 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 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 nonmarginal changes in a nonmarket good, and Rosen (1974) proposed to use the point estimates from the hedonic model to recover an inverse demand function. 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 key aspect of the debate on sustainability is the extent to which natural capital can be viably replaced by other forms of capital. 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 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 helps to answer the call to empirically measure the relationship between natural capital and other forms of capital rather than assume them (Cohen et al., 2019).

In previous first-stage hedonic analyses that consider groundwater, 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 per acre (Brozovic and Islam, 2010; Sampson et al., 2019; Torell et al., 1990) and in the Sacramento Valley of California by \$342 per acre (Bigelow et al., 2019).[1] Second-stage hedonic analyses have an identification problem (Brown and Rosen, 1982). We address this by imposing non-linearity in the hedonic price gradient through a flexible parametric model and estimating separate hedonic price functions for multiple segmented markets and suppose no unobservable differences in preferences across landowners (Bartik, 1987; Bishop and Timmins, 2019; Zabel and Kiel, 2000).

The assumption that preferences and income are similar in all markets has been challenged because people sort themselves through their tastes (Banzhaf and Walsh, 2008). To remedy this, exogenous variables for instruments are necessary, 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 groundwater and the sustainability of natural capital. First, we provide empirical evidence for substitution between groundwater and produced/social capital in some cases, and complementarity with produced/social capital in other cases. Also, we find evidence of substitution between groundwater and human capital. Second, we show that the demand slope is heterogeneous, namely the demand for in situ groundwater is more elastic for rice farmers than for all farm landowners. Third, we estimate a nonmarginal WTP for groundwater when current thickness is between 100 and 120 feet. We find that the WTP for an increase in saturated thickness is \$7.40 per acre-foot for an average farmer, but this ranges from \$2.15 to \$11.40 per acre-foot depending on the produced/social capital available to the farmer.

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 other capital, $K(t)$. The net present value of rents (Eq. 1), which equals the fundamental value for the land, is

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

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 (Dasgupta and Mäler et al., 2000) is

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

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

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),

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

which depends on a vector of observed demand traits, D, affecting the marginal bid. The positive sign in the superscript for K indicates that an increase in K results in a shift outward of Eq. 3 and an increase in p^N. Some of the traits related to producer's management decisions, shown as $x(K,N)$, respond to the evolving stocks of natural and other capital. If there is an increase in other capital K, Eq. 4 shows the shadow price of the natural capital stock after the shift:

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

With the positive sign on the superscript for K, this implies that natural capital and the other capital are complements. To see this, suppose that p^K decreases which leads to a rise in the quantity demanded for K that makes Eq. 4 shift outward. The decrease in p^K (e.g. price of other capital) leads to an increase in the N (e.g. natural capital), indicating that K and N are complements. Likewise, a negative sign on the superscript for K in Eq. 3 indicates that the two are substitutes. A decrease in p^K leads to a rise in the quantity demanded of K that makes Eq. 4 shift inward, and the corresponding fall in the N indicates that K and N are substitutes.

3. Case Study: Groundwater in the Arkansas Delta

We use the responses to a survey of a 2016 sample of irrigators in the Arkansas Delta to test whether produced/social capital, in the form of a network of family or friends who use specific irrigation technologies, and human capital, as an index of years of formal education, affect the shadow price of the saturated thickness of an aquifer, the natural capital stock. Specific irrigation technologies include 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). Also, 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).

3.1. First-stage Data

The first-stage hedonic combines data on agricultural land transactions, soil, climate, irrigation infrastructure, hydrology, and urban influence. The agricultural land sale information comes from

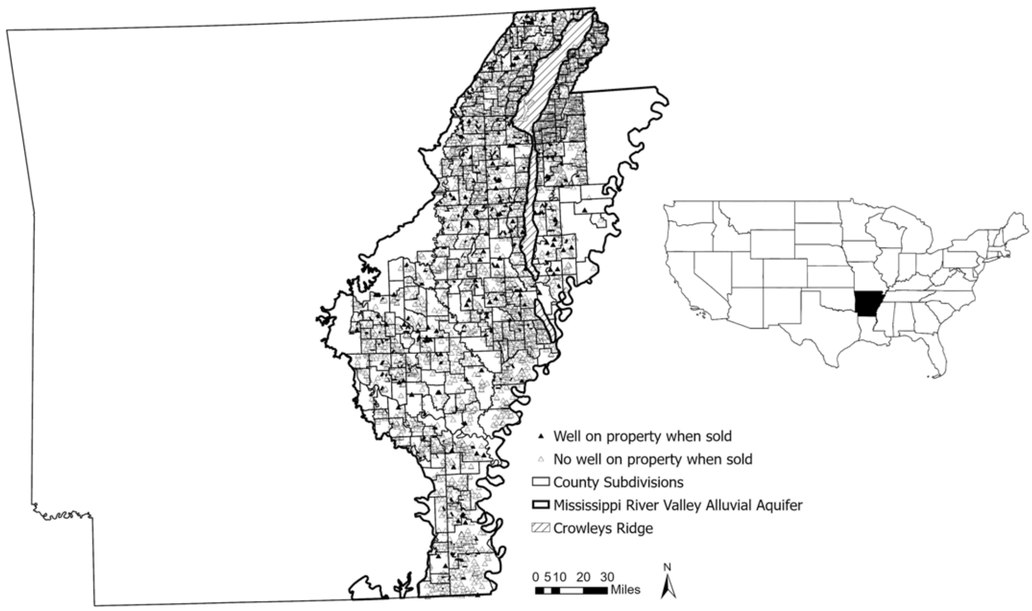

Figure 1. Location of parcels with and without a well when sold and the county subdivision boundaries.

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 and 2019 and is greater than 10 acres in size has a unique identification number for the parcel (Figure 1). The length of the study period raises concerns about the temporal stability of the hedonic price function (Kuminoff and Pope, 2014; Wolf and Klaiber, 2021), and we use controls for groundwater region by year-by-quarter dummies in all hedonic specification to help alleviate this concern (Sampson et al., 2019). We graphically examine the real sale price of agricultural land over the study period and find that these are stable and do not show noticeable deviation from the historical path (Figure A1). 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. 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 3-year rolling average depth to the saturated region of the aquifer[2] from the Arkansas Department of Agriculture, Division of Natural Resources. Figure 2 shows the saturated thickness in 2010, since this is close to the median of the time frame for the land sale transactions that span from 1993 to

[2]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 5-year rolling average measures.

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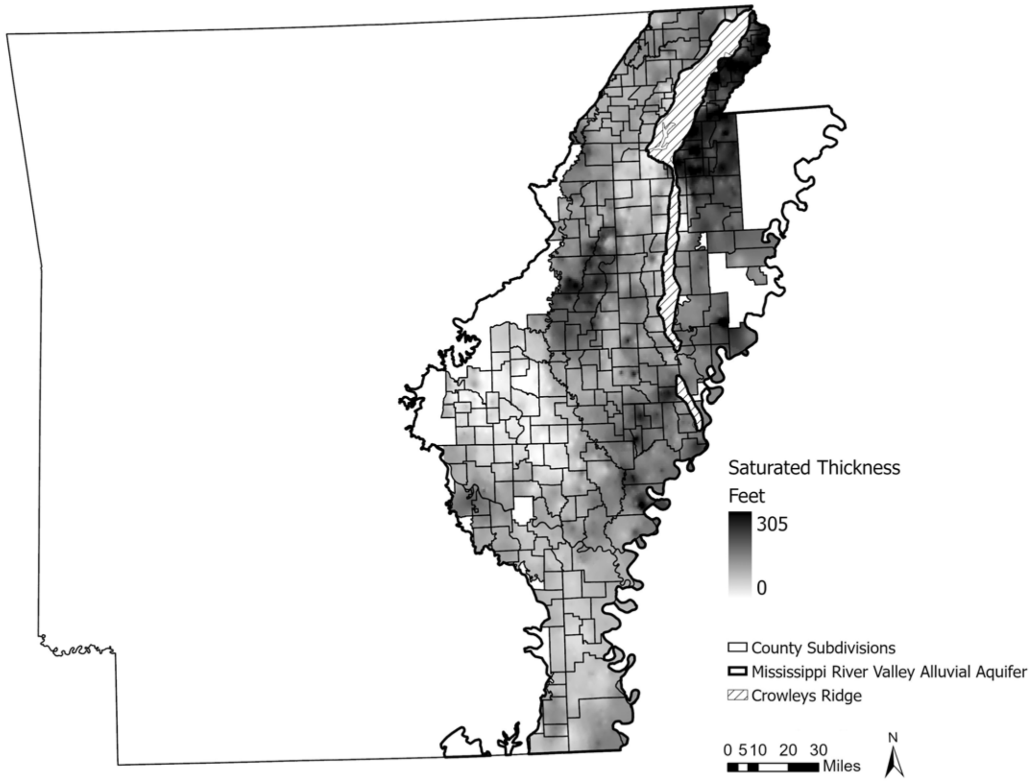

Figure 2. The saturated thickness in 2010 for the Mississippi Valley Alluvial Aquifer.

2019 with most transactions occurring after 2000, and our calculations are consistent with the Arkansas Department of Agriculture and USGS methods 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 A2).

Lateral hydro-conductivity within the alluvial aquifer comes from the spatial interpolation of slug tests by the USGS for 42 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 3-year average, the average number of degree days between 10 and 32°C in the past 5 years, and the average number of degree days when heat harms crop growth (i.e. above 32°C) in the past 5 years (Schlenker et al., 2005). We account for the development option value of the land through controls for urban influence that 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

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

	Well on parcel				No well on parcel			
Variable	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: 3-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: 5-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: 5-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.

dummy variable to indicate the sale of parcels greater than 100 acres as an indicator of purchases by institutional investors who 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.

3.2. Second-stage Data

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. We explored a larger number of groupings for the agricultural land markets than the four in Figure 3 by splitting

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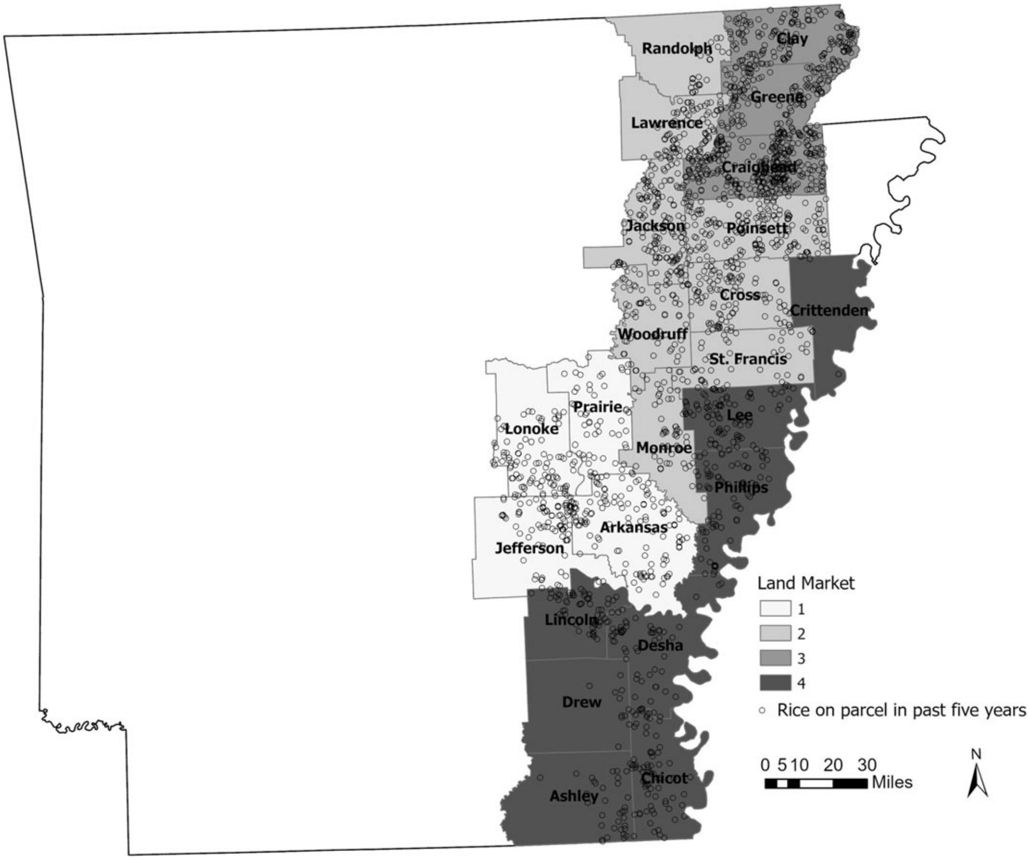

Figure 3. Land markets and the location of parcels with any rice in the 5 years prior to sale.

the region into six and eight agricultural land markets, respectively.[3] The challenge with introducing more agricultural land markets is that justifying each market as distinct and separate is more difficult. The parcels where rice was grown at least once in the 5 years before the sale are also shown in Figure 3 (Johnson and Mueller, 2010). We conduct an analysis using only parcels where rice was grown in the past 5 years to consider the implicit price of saturated thickness where irrigation is greater. Rice is typically grown in rotation with soybeans, and only considering parcels that grew rice in the year of the sale would omit many properties in major rice production regions.

The empirical estimation of the inverse demand for saturated thickness involves combining information from first-stage results with survey responses from farm landowners. Demand shifters that proxy for the type of capital stock (e.g. education is a proxy for human capital) can tell us about whether capital stocks are substitutes. 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 and 40 minutes to finish on average. Of the accessible 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

[3]The implicit price of saturated thickness for the parcels are robust to the different groupings for the agricultural land markets. The hedonic property price results for the six agricultural land market groupings are in Table A5.

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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	First-stage sample mean
SATTHICK	Saturated thickness (feet)	84.01	38.25		119.12
Demand shifters					
LMKT1	= 1 if respondent live in the land market one^	0.14	0.35		0.13
LMKT2	= 1 if respondent live in the land market two	0.39	0.49		0.26
LMKT3	= 1 if respondent live in the land market three	0.16	0.36		0.40
AWS	Available water storage for the top five feet of soil (inches)	13.07	3.05		10.31
PRECIP	Growing season (April to October) precipitation: 3-year average (inches)	27.30	2.34		24.00
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: Number of observations is 182. 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.

and lower household income than the Census of Agriculture, and the mean values for the survey data differ somewhat from the mean values for the data set used in the first stage (Table 2). The saturated thickness is greater with the first-stage data set at 119 feet versus 84 feet for the second-stage data, and the first-stage data occurs less in the land market two and more in the land market three. The available water storage in the top of the soil layer and the growing season precipitation are also lower for the first-stage data.

The survey provides information on the features of the farm such as the number of irrigated acres, and the socioeconomic characteristics such as income, education, and whether peers like

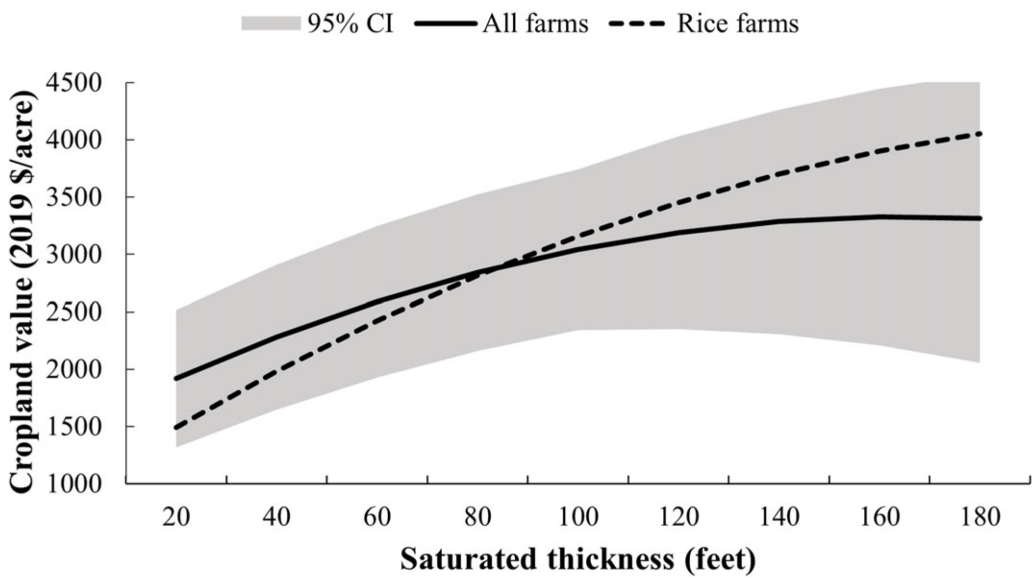

Figure 4. The predicted increase in the value per acre for an average parcel and an average rice parcel associated with saturated thickness based on the inverse demand equation for groundwater.

family and friends used 12 different irrigation techniques in the last 10 years. Summary statistics for the survey variables used as demand shifters and instruments in the second-stage model are in Table 2. Education is a proxy for human capital, and the use of different irrigation techniques by family and friends are proxies for types of produced/social capital that farmers developed within their community. We estimate the saturated thickness for the farms in the irrigation survey using similarities in the data collected for the first-stage hedonic model and the data collected from the irrigation survey. The similar data across the two sources include where the farmer operator lives, the percent of the farmland in corn, cotton, rice, and soybeans, and whether the farm has a reservoir. The coefficient estimates for the prediction of saturated thickness from the data in the first-stage hedonic model are in Table A1. The prediction equation determines the saturated thickness for the farms in the survey using the data from the survey.

4. Empirical Approach

4.1. Identification Problems Related to the Estimation of the Demand for Groundwater

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). Point identification strategies to address the demand slope bias include the nonlinearity 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 nonlinear (Ekeland et al. 2004). Observable farmer characteristics shift the groundwater demand intercept, while the groundwater desired by buyers beneath the farmland adjusts in a nonlinear 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.

We estimate the hedonic price gradient in four separate markets to aid in the point identification. However, while this is necessary, the assumption that the parameters of the demand function

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are the same across markets is not sufficient for identification because of 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, partial identification 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 the most negative estimate (Nevo and Rosen, 2012).

4.2. Estimation of First-stage Implicit Prices

We begin by explaining the procedures for the first-stage hedonic estimation followed by a description of the estimation of demand for saturated thickness in the second stage. The shift of the inverse demand equation by variables that proxy for types of capital stock is what allow us to evaluate substitution among the capital stocks. 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,

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

Estimation of Eq. 5 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 that provides the best fit statistically for each market.

We allow for a nonlinear 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. A quadratic functional form of saturated thickness is simpler, but a nonconstant second derivative on saturated thickness is required for using the curvature of the hedonic equation for identification in the second stage (Bishop and Timmins, 2019). 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

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the parcel.[4] We hypothesize the presence of a well makes buyers concerned 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 $\boldsymbol{\nu}$ indicate that these coefficients, which determine the shape of hedonic price function, are estimated for each land market j. 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 nonlinear 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

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

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 function represented by coefficient estimates in Eq. 6. Saturated thickness affects agricultural land value more for parcels near a well since buyers know groundwater is available for irrigation through a well.

4.3. Estimation of the Second-stage Demand for Groundwater

The second-stage analysis only uses the implicit prices associated with agricultural parcels that have a well on the property. Equation 7 is the inverse demand function for saturated thickness using the implicit prices that come from land market j in Eq. 6 as the dependent variable. We explored log-log and log-linear functional forms of the inverse demand equation, but there is a poor fit for these alternative functional forms.

$$\begin{aligned} p_{SAT} = \alpha_0 + \alpha_1 \mathrm{SATTHICK} + \alpha_2 \mathrm{LMKT1} + \alpha_3 \mathrm{LMKT2} + \alpha_4 \mathrm{LMKT3} + \\ + \alpha_5 \mathrm{AWS} + \alpha_6 \mathrm{PRECIP} + \alpha_7 \mathrm{ACRES} + \alpha_8 \mathrm{INC} + \alpha_9 \mathrm{INC\_NA} + \\ + \alpha_{10} \mathrm{EDU} + \alpha_{11} \mathrm{PEER\_FM} + \alpha_{12} \mathrm{PEER\_AWD} + \alpha_{13} \mathrm{PEER\_TWR} + \mu \end{aligned} \tag{7}$$

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; 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 10 years the farm operator had family or friends (i.e. peers) who use flow meters, alternate wetting and drying, and tail-water recovery, respectively.

The estimates of α on the variables that proxy for the type of capital stock provide the empirical evidence for the substitution among the capital stocks. A positive (negative) coefficient on PEER_FM (α_{11}), PEER_AWD (α_{12}), and PEER_TWR (α_{13}) implies that producers with a peer who use flow meters, alternate wetting and drying, and tail-water recovery systems, respectively, increase (decrease) the shadow price of groundwater, and the groundwater and produced/social capital are complements (substitutes). A negative (positive) coefficient on EDU (α_{10}) means that education decreases (increases) the shadow price of groundwater, and the groundwater and human capital are substitutes (complements).

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

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The implicit price and the quantity of groundwater are set simultaneously within the agricultural land market, and we expect the quantity of groundwater to be endogenous with the implicit price. The quantities of human capital (i.e. education) and social capital (i.e. peers who use flow meters, alternate wetting and drying, and tail-water recovery systems) may also be endogenous through the agricultural labor and land markets. We estimate Eq. 7 through a two-step instrumental variable (IV) generalized method of moments (GMM) estimator, and we test using the GMM *C* (difference-in-Sargan) statistic for an endogenous quantity of groundwater and endogenous quantities of human and social capital (Sargen, 1958).[5] The *C* test statistic is significant for SATTHICK ($p = 0.093$), but not significant for EDU ($p = 0.274$), PEER_FM ($p = 0.315$), PEER_AWD ($p = 0.456$), and PEER_TWR ($p = 0.729$). We caution that the lack of significance in the human and social capital measures can be interpreted as evidence that these are not good proxies for actual human and social capital, which in theory are endogenous.

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 (Wolf et al., 2022). The instrument SI is imperfect because the ranking of saturated thickness by county is correlated with unobservable demand preferences.

A second sorting instrument is the interaction of SI and PEER_TWR. We also call this a sorting instrument because the variable has an interaction with the sorting instrument SI. We examined instruments that interacted SI with other peer group variables, but the instruments did not pass the overidentifying restrictions test (i.e. Hansen's J-test), namely satisfying the hypothesis that the additional instruments are exogenous. The other set of instruments is the land market dummies (LMKT2 and LMKT3) that 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 parcels that produced rice in the last 5 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

[5]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.

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Table 3. Coefficient estimates for the first-stage hedonic model (Natural log of price is the dependent variable)

	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: 5-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: 5-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 population	−0.005[a]	−0.007[b]	−0.0129[a]	−0.016[a]
	(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)

(*Continued*)

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Table 3. (*Continued*)

	No spatial fixed effects	County spatial fixed effect	County subdivision fixed effects	County subdivision fixed effects: Rice^
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 5 years.

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 5 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.

Table 4. Implicit price for a one foot increase in saturated thickness by land market for 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] $p < 0.1$.

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 5 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 positive and significant coefficients on the dummies for the well on parcel and the well within a quarter mile indicate that the potential buyers view wells as valuable irrigation infrastructure for groundwater extraction.

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 of the four land markets.[6] 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 ($8.96 per foot at

[6]The first-stage hedonic estimates for all parcels for the six agricultural land market groupings are in Table A5. The estimates for the four agricultural land market hedonic model with the rice parcels only are in Table A6.

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80 foot saturated thickness) 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, different spatial thresholds of well dummies interacted with saturated thickness, and by only using more recent transactions, those since 2010 and 2015, respectively, that are closer in date to the irrigation survey. 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 spatial extent of saturated thickness capitalization could stretch farther than only for those properties with a well, and we test the assumption by extending the spatial threshold of well proximity to properties within 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). When using more recent transactions in the hedonic model, the implicit price at a saturated thickness of 80 feet increases to \$13.58 per foot when using transactions since 2010 and \$20.03 per foot when using transaction since 2015.

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, like in 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

Once we estimate the inverse demand equation for saturated thickness in the second stage, we can evaluate whether the groundwater capital stock is a substitute or complement with other types of capital. The implicit prices from Eq. 6 are the dependent variable in Eq. 7 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 (Day et al., 2007; Netusil et al., 2010). We use sensitivity analysis with unadjusted prices to assess the impact of that choice on the demand coefficients in Table A7. Saturated thickness sorting indices (SI and SI*PEER_TWR) are the instrumental variables for IV Model 1, and the IV Model 2 has the additional demand shifter IVs (LMKT2_PCTCOT and LMKT3_PCTCOT). The coefficient estimates for the first step of the IV GMM estimator for IV Models 1 and 2 are shown in Table A8. Each IV Model shows the estimation results using the implicit prices from the first step using all parcels (All farms) and using only the rice parcels (Rice farms).[7]

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 −0.178 or more negative, given the positive bias expected even in IV estimation (Nevo and Rosen, 2012). The positive bias on the slope coefficient is evident from the OLS estimation results shown

[7]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.

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Table 5. Coefficient estimates for GMM estimation of the second-stage groundwater inverse demand equation (Implicit price by land market is the dependent variable)

	IV Model 1		IV Model 2	
Variable	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.

in Table A7. 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. 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 greater 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 2016)). The use of in situ groundwater is possible over several years or longer, and the longer time frame within which to use groundwater is one

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explanation for the higher elasticity. Another factor contributing to the higher elasticity is the availability of substitutes for in situ groundwater 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 Eq. 7 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 3 years have weaker preferences for saturated thickness. These coefficient signs match expectations as farmers have 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.

Now we turn attention to the demand shifters that include measures of human and social capital. We do not have a prior expectation for how the level of formal education, i.e. human capital, affects the WTP for saturated thickness. Education was found to have no effect on the WTP for surface water deliveries from irrigation districts in Arkansas (Knapp et al., 2018), and a positive effect on the WTP for on-farm surface water infrastructure (Kovacs and Snell, 2021). The negative sign on EDU in IV models 1 and 2 indicate that more education lowers the WTP for groundwater while potentially increasing it for surface water sources. Natural capital in the case of groundwater in Arkansas appears to be a substitute with human capital.

There are three measures of produced/social capital related to whether the farmer had a close family or friend in the last 10 years who uses a flow meter, alternate wetting and drying, or a tail-water recovery system. 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 use. Some peer networks lead to decision-making that deemphasize natural capital and result in substitution with produced/social capital (i.e. alternative wetting and drying) while other peer networks build complementarities between natural capital and produced/social capital (i.e. flow meters and tail-water recovery systems).

5.2. Rice Farms

To further examine the demand for saturated thickness, we use for the dependent variable in Eq. 7 only the implicit prices from the hedonic model where rice was grown in the last 5 years (Table 5). The rice parcels are spread throughout the study region but concentrated in LMKT1 and LMKT3 (Figure 3). For the rice farms, IV Models 1 and 2 indicate the slope for the saturated thickness demand function is flatter than the all farms estimate. The IV Model 1 slope estimate of the demand function, −0.166, offers more information on the true slope [$-\infty$, −0.166], given the positive bias on slope in the IV model. The LMKT1 dummy has the largest coefficient in the rice farm model, compared to the other land market dummies, while the LMKT3 coefficient is the largest in the all farms model. The own price elasticity of demand by rice farmers, −1.335, is higher than for all farms. The presence of more alternative sources of water for irrigation in rice production areas, namely extensive on-farm surface water infrastructure, may explain the larger elasticity.

The coefficients on the demand shifters have the same sign across the rice farm and all farm versions of the demand model. The substitution relationship between groundwater and human capital is again present with the rice farms. A difference between the rice farm and all farm models

https://doi.org/10.1017/aae.2023.15 Published online by Cambridge University Press

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

Change in saturated thickness(feet)	All farms and land markets				
	Baseline	10% greater EDU	PEER_FM = 1	PEER_AWD = 1	PEER_TWR = 1
20 to 40	362 ± 304	341 ± 282	423 ± 365	257 ± 199	442 ± 384
60 to 80	255 ± 281	236 ± 260	316 ± 342	150 ± 176	335 ± 361
100 to 120	148 ± 257	127 ± 236	209 ± 318	43 ± 152	228 ± 337
140 to 160	41 ± 233	20 ± 210	102 ± 294	–	121 ± 313

95% confidence intervals shown beside each estimate of the per acre property value benefit. The first stage is the cubic specification for saturated thickness and township fixed effects while the second stage is the IV Model 2 for the inverse groundwater demand.

is that the coefficient on PEER_FM is statistically significant in IV models 1 and 2 and the coefficient on PEER_TWR is statistically significant in IV model 2. The same substitution relationship between groundwater and PEER_AWD and the same complementarity relationships between groundwater and PEER_FM or PEER_TWR are present.

5.3. Welfare Calculations

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 160 feet (Table 6). A 20-foot decline in saturated thickness occurs over a period of about 30 years in the overdraft regions of Eastern Arkansas (ADA 2021; ASWCC 2005). The average landowner in all land markets has a saturated thickness of 120 feet, and a decrease in saturated thickness from 120 feet to 100 feet would decrease the per acre property value by $148 for all farms. The positive bias expected on the slope coefficient means that the $148 average for all farms is an overestimate of the decrease in the per acre property value. Landowners with 10% greater formal education than the average, who experience a decrease in saturated thickness from 120 feet to 100 feet, are predicted to have only a $127 decrease in per acre property value. The decrease in per acre property value associated with a decrease in saturated thickness from 120 feet to 100 feet for landowners who belong to a peer group that uses either flow meters or tail-water recovery systems is $209 and $228, respectively, while landowners who belong to the peer group that uses alternate wetting/drying only lose $43.

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 nonmarginal 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). Greater education and cost-share assistance programs help create greater irrigation efficiency and infrastructure that could allow the aquifer to rise by 10 feet over a period of 15 years. Using the irrigated acres by county from the 2017 Census of Agriculture, the welfare increases for irrigated farmers would be $395 million over 4.2 million acres for an average increase in land value per acre of $68. The increase in welfare by land market is $113 million, $76 million, $149 million, and $57 million for land markets 1 through 4, respectively.

6. Conclusion

Properly managing the groundwater means the cost of the groundwater conservation to taxpayers and agriculture must be weighed against the benefits of the conservation. Policy interventions

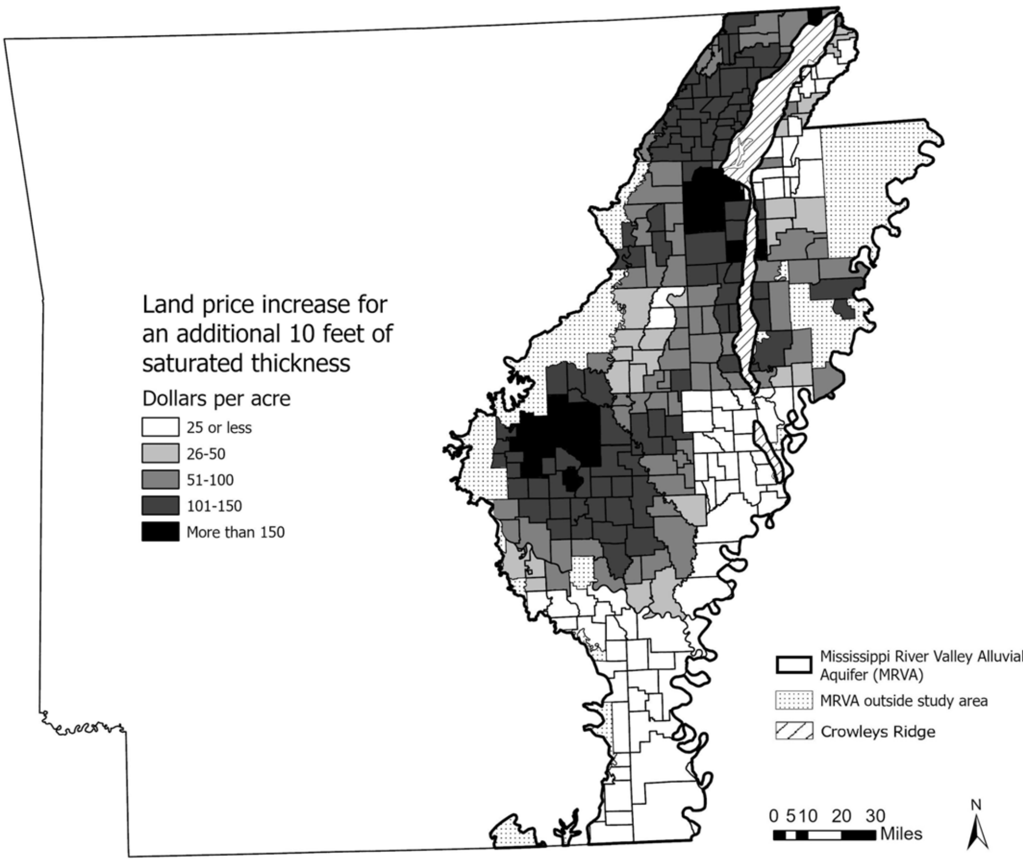

Figure 5. Spatial prediction of the average change in the value per acre of agricultural land associated with a 10foot increase in saturated thickness based on the inverse demand equation for groundwater.

often have the aim of significant increases in groundwater as illustrated by the recent development of California's Sustainable Groundwater Management Act (Kiparsky et al., 2017). However, estimation of a nonmarginal change in the value of groundwater through the use a groundwater demand curve has been a challenge since landowners choose how much groundwater to purchase and the price paid for the groundwater simultaneously. We address this challenge using the nonlinearity in the hedonic price gradient for saturated thickness through a cubic specification (Ekeland et al., 2004) and the estimation of separate hedonic price functions for multiple segmented markets under the assumption of no unobservable differences in preferences across landowners (Bishop and Timmins, 2019).

We contribute to the hedonic literature on groundwater using a panel dataset that comprise agricultural land sales over more than 20 years to determine the welfare implications associated with a nonmarginal increase in saturated thickness. We overcome the problem of assuming a representative landowner across multiple markets when preference-based sorting is present by using IVs suggested by the literature on residential sorting and through primary data collected about irrigator landowners. 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. We predict that average farm landowners in Arkansas lose \$148 in property value per acre from a 120 foot to 100 foot decline

https://doi.org/10.1017/aae.2023.15 Published online by Cambridge University Press

in the saturated thickness, although this is an overestimate given the positive bias on the slope coefficient.

Heterogeneity in the welfare estimates across farms and land markets indicate the importance of policies targeted to specific production activities and regions. Looking at the pooled market estimates for all farms, a 120 foot to 100 foot change in the saturated thickness would underestimate the losses to farms with a tail-water recovery system peer group by $80 but overestimate the losses to farms with an alternate wetting/drying peer group by $105. The differences in the property value losses indicate that not specifying how to apply water policy by irrigation system and cropping activity would lead to inefficiency.

The lack of observable prices for natural capital creates a challenge for the empirical measurement of the substitutability or complementarity between the natural capital and other forms of capital. Shifters of the demand equation include measures of other capital stocks because those other stocks influence people's management of their natural resources. We find that farmers belonging to a peer network who use a new efficient irrigation practice substitute away from groundwater use. However, farmers who belong to a peer network of old irrigation practices have groundwater as a complement. Also, we find that human capital, measured by formal education, and groundwater are substitutes. The relationship between produced/social and human capital and groundwater has not been examined before in the literature.

Central to the sustainability debate are questions around the limits to substitutability and complementarity, and properly measured shadow prices for natural capital are necessary. Our application to groundwater shows that social networks can have a role in systems with interacting human and natural capital stocks. Our approach could be extended to include a greater array of produced capital (e.g. farm equipment and infrastructure) and natural capital (e.g. water and soil quality). Policy makers and natural resource managers can use the empirically measured relationship among the capital stocks to assess tradeoffs in the presence of scarce budgets.

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/aae.2023.15

Data availability statement. The data that support the findings of this study are available from DataScout. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with the permission of DataScout.

Author Contributions. Conceptualization, Kovacs; Methodology, Kovacs; Formal Analysis, Kovacs; Data Curation, Rider and Kovacs; Writing—Original Draft, Kovacs; Writing—Review and Editing, Kovacs; Supervision, Kovacs; Funding Acquisition, Kovacs.

Competing Interests. Authors Kovacs and Rider declare none.

Funding Statement. This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

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Cite this article: Kovacs, K. and S. Rider (2023). "Estimating the Demand for Groundwater: A Second-stage Hedonic Land Price Analysis for the Lower Mississippi River Alluvial Plain, Arkansas." *Journal of Agricultural and Applied Economics* **55**, 194–216. https://doi.org/10.1017/aae.2023.15