Image caption: Irrigated cropland in the Arkansas Delta.

Groundwater and Time Preference Elicitation: Estimating the Value of Market and Non-Market Groundwater Services Over Time

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Abstract: Limited evidence exists about the public's willingness to pay (WTP) and time preferences for sustainable groundwater management policies. Evidence is also limited for how WTP and time preferences relate to market versus non-market groundwater services. We conducted a choice experiment survey in Arkansas, the largest consumer of groundwater in the Lower Mississippi River Basin (LMRB), to jointly estimate the public's WTP and rate of time preference for groundwater preservation in the Mississippi River Valley Alluvial Aquifer (MRVA). Marginal WTP is estimated for groundwater services (certainty of irrigation supply known as buffer value, jobs in agriculture, groundwater quality, wildlife habitat, and avoidance of subsidence) and for two distinct management policies (surface water infrastructure and a cap and trade program for groundwater trading) relative to the status quo of subsidies for best management practices. Results show a significant and positive marginal WTP for buffer value and for jobs from irrigated agriculture, while there is a clear preference for surface water infrastructure investment over a cap and trade groundwater market.

Key Points:

- A choice experiment elicits time preferences for groundwater service values in Eastern Arkansas.
- The largest public values of groundwater relate to agricultural production and water quality, and the policy preference is for surface water infrastructure investment over a cap-and-trade groundwater market.
- Time preferences indicate that the present value of future groundwater services diminishes at an annual exponential discount rate of about 35%.

Introduction

Current policies to mitigate groundwater scarcity mostly involve voluntary incentive programs that target agricultural users because they hold long-term financial interests linked to groundwater availability. However, aquifer depletion continues and even accelerates in many agricultural production regions despite current management efforts (Konikow, 2015; Schaible and Aillery, 2012), warranting deeper policy consideration. Efficient policies consider values to society rather than only to the marketplace. The benefits of groundwater cannot be appropriately valued solely on market forces, and a better framework considers the importance of groundwater across all of its values to society.

This study focuses on the Mississippi River Valley Alluvial Aquifer (MRVA), a valuable water resource asset economically and strategically that supports intensive irrigated crop production in the Lower Mississippi River Basin (LMRB). High levels of groundwater use and expanding irrigated acreage have drawn down groundwater levels in the MRVA, and the current rate of withdrawal threatens the long-term viability of irrigated agriculture in the region. More than 98% of water use from the MRVA goes to support agricultural irrigation (USDA, 2013), and current valuation and management of the groundwater focuses on its extractive uses.

Consideration for the total economic value (TEV) of groundwater is crucial for estimating the net benefits of potential policies and management actions. Furthermore, policymakers would benefit from greater knowledge about how groundwater's social value disaggregates among its constituent components: market and non-market values, or direct use values (i.e., extractive uses), passive use values (e.g., subsidence avoidance), non-use values (i.e., use by others or by future generations), and option values (i.e., ensuring the option to use in the future). Identifying all groundwater services within a region and then estimating the public's WTP for preserving each of those services provides a detailed starting point for estimating these component values. There is however limited empirical evidence about the public's WTP for preserving groundwater in aquifers facing depletion due to irrigated agriculture. Beyond TEV, even less is known about the relative values placed on the existing flows of groundwater services.

The dynamics of aquifer depletion and recharge are complex, and meaningful resource change occurs over decadal timescales, which complicates valuation and policy deliberation. This makes understanding the time preferences for the flow of groundwater services vital for appropriately managing them. Hence, joint modeling of the annual flow of groundwater services and time preferences is important. This also allows policymakers to calculate the TEV with social discount rates. The literature has widely observed that individuals have high rates of discounting (Meier and Springer, 2010; Frederick, 2002). But social investments are typically made with social discount rates rather than individual discount rates. By separating the value of annual groundwater services from individual time preferences, a recalculation of the TEV with social discount rates is possible. This provides policymakers with a social TEV to weigh against the policy costs when evaluating social projects.

The optimal framework for valuing groundwater considers not only hydrologic factors and the aggregation of all existing flows of groundwater services, but also temporal and policy contexts. The value of groundwater is affected by circumstances, and only a limited number of studies explore groundwater valuation across alternative policy contexts or in contexts that incorporate realistic environmental timescales and time discounting. Potential policy initiatives for addressing groundwater decline include improved irrigation efficiency, surface-water infrastructure projects, managed aquifer recharge (MAR), and the establishment of groundwater marketplaces to facilitate regional pumping caps and efficient trading of allocated pumping permits (Reba et al., 2017; Chong and Sunding, 2006).

The objective of this research is to conduct a choice experiment (CE) in order to estimate total WTP for groundwater preservation under different policy alternatives, as well as marginal WTP for existing groundwater services and rates of time preference. We conducted the CE survey in Arkansas, the largest consumer of MRVA groundwater, and then estimated the marginal WTP values for groundwater services (certainty of irrigation supply known as buffer value, jobs in agriculture, groundwater quality, wildlife habitat, and avoidance of subsidence) and for two distinct management policies (surface water infrastructure and a cap and trade program for groundwater trading) relative to the status quo of subsidies for best management practices. We also estimated time preference parameters associated with the costs and benefits of long-term groundwater management.

Methods

Intertemporal Utility and Time Preference Functions

Public goods policies such as those for the long-term management of groundwater resources exemplify choices that realize benefits and costs at different points in time. Money invested today in groundwater savings can produce benefits that continue into the future. In fact, meaningful benefits from groundwater savings may not accrue or begin to be realized until a policy has been underway for some years. Individuals typically discount the utility they receive from future outcomes relative to the utility of current outcomes. Samuelson (1937) developed the first discounted utility model for intertemporal choice commonly known as the exponential discounting model, estimating a single discount rate parameter. This is the standard model for intertemporal utility, largely because of its simplicity (Meyer, 2013a; Frederick, 2002). The exponential discounting function takes the form of

$$U(c_0, c_1, \dots, c_T) = \sum_{t=0}^{T} \psi_t u(c_t),$$

where the discount factor for year t is $\psi_t = \left[\frac{1}{1+\rho}\right]^t$ and ρ is the discount rate.

We integrate this time preference function into a discounted utility model similar to Meyer (2013a; 2013b).

Empirical Model

To analyze discrete choice data involving intertemporal goods, let the instantaneous utility for individual *i* alternative *j* in choice situation *k* and period *t* be given by

$$u_{ijkt} = v_{ijkt} + \xi_{ijkt}.$$

The term, u_{ijkt}, contains a vector of fixed coefficients and a vector of observed variables, while ξ_{ijkt} is the instantaneous error draw. The additively separable utility through time period *T* is given by

$$U_{ijk} = \sum_{t=0}^{T} \psi_t u_{ijkt} = \sum_{t=0}^{T} \psi_t v_{ijkt} + \varepsilon_{ijk},$$

where ψ_t is the discount factor for year *t* and $\varepsilon_{ijk} = \sum_{t=0}^{T} \psi_t \xi_{ijkt}$ is the weighted sum of all instantaneous error draws, weighted each period by the discount factor, ψ_t. We assume that v_{ijkt} depends upon a bundle of alternative-specific groundwater service attribute levels in time period *t*, including benefits, x_{ijkt}, and the cost, p_{ijkt}. The multinomial logit (MNL) specification is then

$$U_{ijk} = \sum_{t=0}^{T} \psi_t \left(-\lambda p_{ijkt} + \boldsymbol{\beta}' \ \boldsymbol{x_{ijkt}}\right) + \varepsilon_{ijk},$$

where ε_{ijk} is distributed i.i.d. Type I Extreme Value.

Respondent *i* chooses alternative *j* in choice situation *k* if $U_{ijk} > U_{imk} \ \forall m \neq j.$. The probability that individual *i* chooses alternative *j* in choice situation *k* is given by,

$$\boldsymbol{P}_{in_{ik}kt} = \frac{\exp(\sum_{t=0}^{T} \psi_t \left(-\lambda p_{ijkt} + \boldsymbol{\beta}' \ \boldsymbol{x_{in_{ik}kt}}\right)}{\sum_{j=1}^{J} \exp(\sum_{t=0}^{T} \psi_t \left(-\lambda p_{ijkt} + \boldsymbol{\beta}' \ \boldsymbol{x_{ijkt}}\right)}$$

The Log-likelihood function is then,

$$LL(\boldsymbol{\beta}, \lambda) = \sum_{k=1}^{K} \sum_{i=1}^{I} \ln\left(\frac{\exp(\sum_{t=0}^{T} \psi_t \left(-\lambda p_{ijkt} + \boldsymbol{\beta}' \ \boldsymbol{x_{in_{ik}kt}}\right)}{\sum_{j=1}^{J} \exp(\sum_{t=0}^{T} \psi_t \left(-\lambda p_{ijkt} + \boldsymbol{\beta}' \ \boldsymbol{x_{ijkt}}\right)}\right)$$

We estimate the model using Maximum Likelihood Estimation (MLE) and a version of the GMNL package in R that has been modified to include the joint estimation of time preference. We include alternative-specific constants (ASCs) that represent choice alternatives different from the reference status quo. To avoid imposing the unrealistic data requirements necessary for estimating ψ_t, structure can be placed on the type of discounting using the exponential discounting formula described in the section above so that we can estimate ψ_t at any time *t* (Meyer, 2013a).

Questionnaire and Experimental Design

For eliciting groundwater and time preferences, we chose to conduct a CE involving MRVA outcomes. Respondents choose among three groundwater management policy alternatives, including a surface water infrastructure (SWI) alternative, a cap and trade (CAT) alternative, and a status quo (SQ) alternative involving no change to current MRVA groundwater management. Information about each alternative is clearly provided to survey respondents, and each respondent must successfully answer comprehension questions about each alternative before advancing in the survey.

To determine the most appropriate attributes for the CE design, we conduct a focus group and collect information about the socio-environmental services people value from MRVA groundwater. Focus group participants reviewed survey questionnaire sections related to the MRVA and potential policy alternatives, discussing clarity, comprehension, and difficulty. This feedback, together with existing conceptual frameworks for groundwater valuation (NRC, 1997), guide the selection of the CE attributes. There are five main groundwater services, or attributes, that we identify contributing to the MRVA's TEV. These are water quality for irrigated agriculture, the provision of jobs in the agricultural economy, the provision of habitat for maintaining wildlife, especially fish and waterfowl for local tourism, the avoidance of subsidence and its associated infrastructure costs, and the certainty of adequate water supply in case of drought (buffer). We rely on existing hydrologic (Clark et al., 2013) and economic (Kovacs et al., 2015) simulation models to help in setting realistic attribute levels for the SQ alternative. The attributes and levels in our CE are shown in Table 1.

We express all attribute levels as percentage values in order to lessen the difficulty of comparing alternatives across multiple attributes. Levels indicate outcomes for the year 2050 and appear in terms of a percentage of current levels, so that 100% indicates no change from current levels. We include a cost attribute using an increase to state income taxes for the household as the payment mechanism.

To identify time preferences, we employ a split-sample design and vary the timing of the expenses associated with the cost attribute. There are treatments for the cost attribute that include perpetual annual payments beginning in the current tax year, perpetual annual payments beginning in the following tax year, a single lump payment for the current tax year, and a single lump payment for the following tax year. By varying the onset and duration of the payment mechanism in the choice sets, estimation of the time preference parameters within the discount factor for the exponential, hyperbolic, and quasi-hyperbolic functional forms is possible (Meyer, 2013a; 2013b). The range of the lump payment

Table 1. Experiment attributes and definitions.

Attribute	Definition	Levels[a,b]
Buffer Quantity	The percentage of current acres with adequate groundwater for 5 consecutive drought years	25%, 40%, 55%, 70%
Water Quality	The percentage of current acres with adequate groundwater quality for irrigation	75%, 80%, 85%, 90%
Jobs from Irrigated Agriculture	The percentage of current (120,000) jobs	80%, 90%, 100%, 110%
Wildlife Diversity & Abundance	The percentage of current wildlife diversity and abundance	75%, 80%, 85%, 90%
Infrastructure Integrity	The percentage of current infrastructure integrity	75%, 80%, 85%, 90%
Cost to Household (lump)	The dollar increase in state income taxes	$0, $30, $90, $150, $210, $270
Cost to Household (perpetual)	The dollar increase in state income taxes	$0, $12, $24, $36, $48, $60

[a] The status quo levels are indicated in bold

[b] Levels indicate outcomes for the year 2050 and 100% indicates no change from current levels

cost attribute levels is similar to Meyer (2013a; 2013b) and Viscusi et al. (2008). Following Egan et al. (2015), we convert lump payment levels to perpetual payment levels using a 25% discount rate and rounding to equal-interval dollar amounts.

This study elicits preferences for long-term groundwater management policies implemented at the state level. We concentrate on sampling voting-aged residents of Arkansas, where the dominant portion of the MRVA is located and the most groundwater use occurs. Between August 27th and October 17th of 2018, we administered a stated preference survey regarding long-term MRVA groundwater management and outcomes using the survey research firm, Qualtrics. Approximately 2000 adult residents of Arkansas voluntarily accessed the four versions of the internet-based survey from proprietary research panels and other internet sources. The survey is designed to be compatible with both traditional and mobile internet platforms. Individuals receive financial incentive for participating in Qualtrics surveys. Qualtrics pre-filters responses to remove any potential duplicate from a single individual or any observation with a total response time less than one-third the median total response time. Observations that are incomplete are dropped from the analysis, leaving 782 usable survey responses and data for 3,910 choice occasions.

Results and Discussion

Overall, the sample is a close representation of the target population. Relative to the general population of Arkansas residents, our sample shares characteristics for median income and unemployment rate while being slightly older (median age 42 compared to 38), more female (66% to 51.5%), and more educated (30.3% with bachelor's degree to 23.4%) (US Census Bureau, 2018). Statistics on voters and registered voters in the US suggest that the voting electorate shares these same biases relative to the general population (File, 2018), supplying added confidence in the validity of the stated preferences for groundwater policies. Table 2 provides summary statistics for sample demographics. The spatial distribution of the sample also closely represents Arkansas's actual population density. Comparing sample proportions across Arkansas's 75 counties to the Census population proportions using the Mann-Whitney test shows no significant difference (p-value=0.247).

Table 3 shows the results from the joint estimation of the MNL model, including the estimated annual discount rate, preference coefficients for market and non-market groundwater services, and the ASCs for each policy alternative. Marginal WTP present values are computed and reported in Table 4. Results indicate significant and positive preferences for buffer, water quality, and jobs from irrigated agriculture. The policy preference is clearly for current sub-

Table 2. Sample demographics.

Characteristic	MRVA Survey Sample	Arkansas Population
Median Age	42	38
(standard deviation)	-15.29	
Percent Female	66	51.5
(standard error)	-0.017	
Mean persons per household	2.85	2.53
(standard deviation)	-1.27	
Median household income	$ 40,000 - $ 49,000	$45,869
Percent high school degree or higher	95.3	86.7
(standard error)	-0.008	
Percent bachelor's degree or higher	30.3	23.4
(standard error)	-0.016	
Percent married	57.9	49.2
(standard error)	-0.018	
Percent Unemployed	6.3	5.6
(standard error)	-0.009	

Table 3. Model results.

Parameter	Estimate	P-value
Exponential-r	0.353	< 0.001***
	-0.050	
ASC.SW	-0.085	0.465
	-0.117	
ASC.CAP	-0.249	0.0350**
	-0.118	
Buffer	0.070	0.0009***
	-0.021	
Quality	0.122	0.0148**
	-0.050	
Jobs	0.072	0.0155**
	-0.030	
Wlife	0.042	0.288
	-0.040	
Infra	0.039	0.329
	-0.040	
Cost	-0.010	< 0.001***
	-0.001	
LogLiklihood		-4212.5

Table 4. Marginal willingness to pay (WTP) results.

Marginal WTP	
ASC.SW	-8.714
ASC.CAP*	-25.357
Buffer*	7.122
Quality*	12.490
Jobs*	7.306
Wlife	4.316
Infra	3.959

*Computed from significant MNL estimates

sidy programs over the initiation of a cap-and-trade groundwater market. Any differences in preference between the status quo and new investments in surface water infrastructure are not indicated to be significant. The greatest marginal WTP is for the provision of the water quality service (about $12 per 1% increase over 30 years), while buffer and jobs are valued similarly (about $7 per 1% increase over 30 years). The joint estimation indicates an annual exponential discount rate of 35%.

Conclusions

We conduct a choice experiment in Arkansas to estimate preferences for groundwater services in the MRVA. The results of the MNL estimation support the conclusion that Arkansas residents value groundwater in the alluvial aquifer primarily for its provision of services related to agricultural production. These constitute use values of the groundwater, and current policies are aimed at maintaining the groundwater's use values. The lack of any significant preference for wildlife service provision or subsidence avoidance shows there is no evidence for any desired shift in current policies.

The same conclusion is supported by the ASCs for alternative policies. The ASC for a cap-and-trade groundwater alternative is significant and negative, indicating a strong preference for the status quo. The ASC for additional investment in surface water infrastructure is not significant. It may be that close similarities between the surface water infrastructure alternative and the status quo explain this similarity in policy preference between them, as surface water infrastructure impoundments are an important component of current best management practices.

Water quality provision that is adequate for agricultural irrigation has the highest marginal WTP valuation among the groundwater services. This compares predictably to other literature that shows very high preferences for attributes related to food safety (Bazzani et al., 2018), which may be a driving concern when considering water quality for agricultural irrigation.

Relative to similar studies that use stated preference methods to empirically estimate a social discount rate for environmental improvements, we estimate an annual exponential discount rate with a similar, but slightly larger magnitude. Meyer (2013a) and Meyer (2013b) find annual discount rates that range from about 10% to about 13%. Viscusi et al. (2008) finds an annual discount rate that ranges from about 8% to over 14%. They observe a discount rate as high as 22.9% for people who make no use of the environmental area in question. Though lower than our estimated annual discount rate of 35%, the differences are not large and could reflect systematic differences between target populations of the respective studies. Meyer targets residents of Minnesota and Viscusi a nationwide sample, while we examine preferences of Arkansas residents. Compared to Minnesotans and the nation at large, Arkansas residents in our study demonstrate a higher rate of time preference, meaning they place greater weight on present benefits relative to future ones.

A higher rate of time preference theoretically translates to lower social investment in future benefit streams. The results of our survey indicate that current groundwater policies in the state of Arkansas, though perhaps insufficient to reverse the trend of groundwater depletion present in the MRVA, are well aligned with the overall policy preferences of Arkansas residents. There is no evidence of any preference either for a paradigmatic shift in policy (i.e., cap-and-trade groundwater market) or a significant increase in investments for surface water infrastructure projects. Continuing research should seek to better understand segments of the population that possess significantly different groundwater preferences and examine the spatial or socio-demographic characteristics that might be driving those differences. These differences could have meaningful implications for indicating the most appropriate scale or policy arena in which to advance new long-term groundwater management policies.

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