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RESEARCH ARTICLE

Public Willingness to Pay for Farmer Adoption of Best Management Practices

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Abstract
This paper analyzes public willingness to support farmer adoption of best management practices in Oklahoma's Fort Cobb Watershed, a multiuse area for agriculture, residential water provision, and recreation. The study uses Oklahoma's Meso-Scale Integrated Sociogeographic Network survey to conduct a contingent valuation analysis of a hypothetical, one-time tax that would support farmer adoption of pasture and riparian buffer management practices. Respondent heterogeneity is modeled using beta-binomial regression. Public support for the hypothetical program is stronger for the tandem implementation of riparian buffer establishment and pasture expansion (willingness to pay [WTP] = $290) and riparian buffer establishment (WTP = $317).

Keywords: best management practices; beta-binomial regression; Hamiltonian Monte Carlo Markov chain; water quality; willingness to pay

1. Introduction

Best management practices (BMPs) are working farmland practices designed to reduce the off-site effects of farming on water quality and soil resources (Aillery, 2006). The voluntary adoption of BMPs by agricultural producers and landowners is one solution toward repairing and sustaining watershed functions that are susceptible to the unintended by-products of agricultural production (Diebel et al., 2008; Hansen and Hellerstein, 2006; Makarewicz et al., 2009; Ribaudo, 2015; USDA NRCS, 2011a, 2011b, 2011c; USDA NRCS, 2012). Changes in market conditions, or revisions to state or federal conservation policies, can influence producer decisions to adopt conservation practices (Hellerstein, 2010; Prokopy et al., 2008; Qiu and Prato, 2001; Rafuse, 2013; Schaible et al., 2009; Stuart and Gillon, 2013). The maintenance and provision of environmental services may require government intervention on behalf of nonagricultural stakeholders (Ostrom, 1991).

United States Department of Agriculture (USDA) programs targeting watershed improvement through BMP adoption pay agricultural producers to modify voluntarily their production practices. Examples of BMPs are the retirement of environmentally sensitive land, adoption of cover crops, use of reduced tillage practices, installation of conservation buffers, and the conversion of cropland to pasture. The USDA's Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA) promote and coordinate the voluntary adoption of BMPs through multiple programs (Stubbs, 2020). These programs offer federal and state financial and technical support to encourage BMP adoption by agricultural producers and landowners. Eligible producers can receive payments to retire land from crop and livestock production for 10–15-year contracts with the assistance of the FSA's Conservation Reserve Program (CRP) (Sullivan et al., 2004). Some CRP programs support working farmland conservation measures, including riparian buffers,

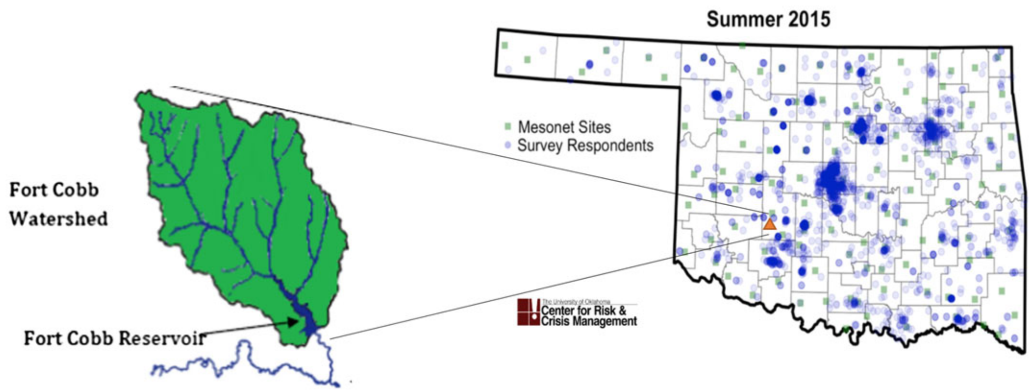

Figure 1. Fort Cobb reservoir and the locations of surveyed households.

contouring, and wildlife habitat enhancement (Aillery, 2006). The Conservation Stewardship Program (CSP) and Environmental Quality Incentive Program (EQIP), both managed by the NRCS, also provide cost-share options for implementing BMPs on working farmland and pasture (Cattaneo, 2003; Claassen, Cattaneo, and Johansson, 2008; Lambert et al., 2007; Lichtenberg and Smith-Ramirez, 2011; Ren et al., 2021).

Research on BMP adoption from the producer's perspective is extensive (Adusumilli et al., 2020; Baumgart-Getz, Prokopy, and Floress, 2012; Boyer, Tong, and Sanders, 2018; Claytor et al., 2018; Gillespie, Kim, and Paudel, 2007; Ren et al., 2021; Jensen et al., 2015; Kim, Ferrin, and Rao, 2008; Lambert et al., 2020; Liu, Bruins, and Heberling, 2018; Mishra et al., 2018; Prokopy et al., 2019, 2008; Roberts et al., 2004, Tong, Boyer, and Sanders, 2017). Less frequent are survey studies on the nonagricultural public's willingness to pay (WTP) for programs that provide financial support to farmers for adopting BMPs.

This research estimates citizen WTP to support farmer adoption of BMPs to enhance water quality and moderate soil erosion in Oklahoma's Fort Cobb watershed (FCW). The practices examined are the conversion of cropland to pasture (an activity supported by the CSP and the Grassland Conservation Initiative) and the establishment of riparian buffers (EQIP Programs 390 and 391). In the case of the FCW, a resource allocation inefficiency results from negative externalities that arise from land management decisions by private farms and ranches upstream of the Fort Cobb reservoir (FCR), a multiuse water body servicing agricultural and nonagricultural uses. Allowing livestock unrestricted access to streams and waterways can cause stream bank degradation, soil erosion, and diminish water quality. The costs associated with underuse of soil-conserving practices and stream bank degradation are eventually borne by nonagriculturalists and experienced as a reduction in recreational enjoyment of the FCR's amenities or as a reduction in the water withdrawn for nonrecreational uses. The effects of water quality deterioration are passed on to downstream users and the public in the form of increased drinking water treatment costs, reduced hydroelectric capacity, and fewer recreational days. WTP is estimated using data from a 2015 hypothetical, contingent valuation (CV) survey of Oklahoma citizens. The survey data are from the Oklahoma Meso-Scale Integrated Sociogeographic Network (M-SISNet)[1] (Figure 1). Beta-binomial regression, a parsimonious alternative to random parameter models for incorporating unobserved heterogeneity into estimating equations, is used to estimate WTP.

[1]Survey documentation and data are available at http://crcm.ou.edu/epscordata/.

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2. Study Area

The FCW is located in southwestern Oklahoma (Figure 1) and encompasses about 200,000 acres and supports row crop and forage agriculture. Approximately 90% of the watershed's land area is used for agriculture, with more than half of the land used to produce row crops and the remainder in pasture (Becker, 2011). Over 80% of the watershed's soils are classified as highly erodible sandy clays and loams (OCC, 2009). There are mixed agricultural land uses including rangeland and pasture (41%), dryland crops (41%), irrigated crops (10%), forest (6%), and water (2%). Crops in the FCW are irrigated with center pivot systems on sandy soils supplied by groundwater. Stocker cattle are typically grazed on FCW range and pasture. Confined swine operations are also located in the upper portion of the watershed (USDA, 2016).

The FCR was constructed in 1958 as a part of the Bureau of Reclamation's Washita Basin Project. Located in Caddo County, the FCR covers approximately 4,000 acres (16 km^2) with water, with 45 miles (72 km) of shoreline and a drainage area totaling 285 square miles (740 km^2). Since its completion, the FCR and its tributaries throughout the watershed have been providing citizens opportunities for various outdoor recreation activities, supplying water to municipal and industrial users, and flood control. In 2013, Fort Cobb State Park generated about $328,000 in revenue (Caneday, Liu, and Tapps, 2015). More than 37,970 sportfishing trips on the FCR and its tributaries were registered in 2014, and these trips generated over $1.8 million from angler spending (Melstrom et al., 2017). FCR also supplies water to Anadarko and Chickasha cities, the Western Farmers Electric Cooperative, and the Public Service Company of Oklahoma.

Water quality problems in the FCR were first identified in 1981 (OCC, 2009). In 2014, Oklahoma Water Quality (OKEQ) data documented that *Escherichia coli* and *Enterococcus spp*., in addition to eutrophication caused by phosphorus loading, surpassed TMDL targets in the reservoir and its tributaries (OKEQ, 2014). By 2016, public and private use of FCR water was suspended due to Chlorophyll-a blooms, which eventually caused fish kills (OKEQ, 2016). In 2018, the same bacteria and algae impaired the FCR and its tributaries (OKEQ, 2018). Studies concluded that the main cause of biological, chemical, and habitat degradation of the FCR and its water segments were excess nutrient and sediment runoff from crop and livestock production above the reservoir (Fox et al., 2016). About 46% of the sedimentation occurring in the FCW comes from eroded cropland soils (Wilson et al., 2008). Conversion of 20% of the FCW's cropland to pasture would cost 2.1 million dollars to meet a sediment reduction goal of 30% and a phosphorous loading reduction of 22% (OCC, 2009). A 2009 report by the Oklahoma Conservation Commission (OCC) estimated that the installation of riparian buffers on 60% of the FCW area would result in a reduction in sedimentation by 75–90%, and a decrease in phosphorus runoff into the reservoir by 40–60% (OCC, 2009). The same report estimated that the total funding required to achieve a total maximum daily loading target (TMDL) of 30% would be 11 million dollars.

3. Previous Research

Implementation of conservation practices can generate measurable reductions in watershed nutrient runoff and sediment yield (Garbrecht and Starks, 2009; Prokopy et al., 2019; Singh, Saraswat, and Sharpley, 2018; Starks et al., 2014; Uniyal et al., 2020; Wallace, Flanagan, and Engel, 2017). The effects of conservation practices on sediment yield and nutrient runoff vary by watersheds. Bosch et al. (2013) found that cover crops, filter strips, and minimal tillage practices were the most effective measures to mitigate nutrient runoff and sediment yield in Lake Erie's watersheds. Merriman et al. (2019) concluded that establishing permanent brome grass reduced sediment yields in the Great Lake region's watersheds. Gharibdousti, Kharel, and Stoecker (2019) found that converting cropland to perennial grasses in the FCW could reduce sediment yield by more than 70%.

The state of Oklahoma supports conservation practices in the FCW, along with federally supported conservation programs that offer cost-sharing opportunities to foster BMP adoption

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(USDA, 2016). These programs have had some success in moderating soil erosion and sediment runoff in the study region, but the FCR and its water segments remain susceptible to impairment. Boyer, Tong, and Sanders (2018), and Tong, Boyer, and Sanders (2017) estimated FCW producer willingness to adopt conservation practices. Their research concluded that both outreach and economic incentives would be required to encourage the adoption of soil and water conservation practices among FCW landowners and operators. To the authors' knowledge, little research has been conducted on the public WTP to support landowner and operator adoption of BMPs in FCW.

WTP for environmental goods, such as water quality, quantifies how much private users, or the public, would pay to enjoy the use of the good or to sustain its existence value (Carson and Mitchell, 1993; Goulder and Kennedy, 1997; Jørgensen et al., 2013; Krutilla, 1967; Randall and Stoll, 1980; Weisbrod, 1964). Estimation of WTP is typically based on CV methods (Habb and McConnel, 2002). Gramlich (1977) analyzed household survey data to estimate WTP for swimmable water in Boston, Massachusetts's Charles River. Research on WTP to improve lake and stream water quality for recreational opportunities has been conducted in the South Platte River Basin (Greenley et al., 1981). WTP for better drinking water has also been estimated to assist water resource managers in fee structure design (Chatterjee et al., 2017; Jordan and Elnagheeb, 1993; Tanellari et al., 2015). Lewis et al. (2017) elicited resident WTP for riparian zone projects in urban watersheds. Aguilar, Obeng, and Cai (2018) found that people were willing to pay to improve water quality and, more generally, for ecosystem service provision. Johnston and Thomassin (2010) and Huber and Richardson (2016) summarized other research on WTP for lake and stream water quality.

4. Data

We use Oklahoma's M-SISNet survey to estimate state residents' use and existence value of the FCR and its tributaries. The M-SISNet surveys collect data on household perceptions and outlook toward climate change and extreme weather events. Additional questions focus on household views on government policy, societal issues, and how viewpoints and opinions influence citizen perceptions of energy and water use. Jenkins-Smith et al. (2017) provide details on the survey sampling methodology. There are 22 survey waves. Each wave was launched in spring, summer, fall, and winter, from 2014 to 2020. This study uses Wave 7, which was conducted in summer 2015. Wave 7 surveyed 2,532 randomly selected Oklahoma households (Figure 1). Wave 7 is the only M-SISNet survey that included a CV question related to the FCW and its reservoir.

In addition to citizen opinions on societal issues, climate, and water and energy consumption, a hypothetical referendum pertaining to the FCW and its reservoir's water quality was conducted as a CV exercise. Discussion of the demographic and CV variables included in the statistical model follows. Variable names included in the statistical analysis are italicized. Respondents were provided background information about the watershed, including a map and diagram of the watershed's location and its functional uses including recreation, agriculture, water provision, and flood control. Respondents were asked how familiar they were with the FCW (*familiar*, Likert scale; 1 = not at all familiar, 4 = very familiar), if they used the reservoir for recreation (*lakerecreate*, 1 = yes, 0 otherwise), and the number of visits to the reservoir over the past 5 years (*resvisit*, count). Respondents also read brief descriptions of the ecosystem services provided by the FCW, including land for agriculture, water filtration, erosion control, and wildlife habitat.

4.1 Demographic Variables

Demographic variables include respondent age (*age*, years), if the respondent had a college degree (*college* = 1, 0 otherwise), respondent sex (*male* = 1, 0 otherwise), and if the respondent was white (*white* = 1, 0 otherwise) (Table 1). The average age of respondents was 59, 60% of respondents

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Table 1. Variable names and CRMC 7 survey summary statistics

Variable name	Variable description	Units	Mean	Standard deviation	Min	Max
age	Age	Years	58.85	14.17	19	98
male	Male	(1 = yes)	0.6		0	1
college	College degree	(1 = yes)	0.29		0	1
white	White	(1 = yes)	0.88		0	1
hhsize	Household size	Count	5.58	3.79	2	14
own	Home ownership	(1 = yes)	0.89		0	1
ranch	Farm or ranch	(1 = yes)	0.27		0	1
lakerecreate	Used Ft. Cobb for recreation	(1 = yes)	0.43		0	1
resvisit	Number of times/year visited	Count	1.31	9.45	0	300
familiar	Familiar with Ft. Cobb watershed	(Likert scale: 1 to 4)	1.43	0.75	1	4
algae	Algae reduction potential	random (25, 50, 75, 100%)	61.34	27.98	25	100
benclean	Benefit: clean water	(1 = yes)	0.45		0	1
benerode	Benefit: reduce erosion	(1 = yes)	0.1		0	1
benag	Benefit: agriculture	(1 = yes)	0.25		0	1
benwild	Benefit: wildlife	(1 = yes)	0.18		0	1
costcommerce	Factor score: commercial and supporting activities	Standardized	0	1.00	−2.84	2.22
costsocial	Factor score: socio-economic concerns	Standardized	0	1.00	−2.50	2.74
confident	Confidence in survey 1	(Likert scale: 0 to 10)	4.21	2.60	0	10
majority	Confidence in survey 2	(1 = yes)	0.34		0	1
attentive	Survey attentiveness	(1 = yes)	0.57		0	1
distance	Distance to Ft. Cobb	Miles	98.67	53.03	1.41	239.54
pasture	Yes – pasture	(1 = yes)	0.62		0	1
buffer	Yes – riparian buffer	(1 = yes)	0.68		0	1
pasture-buffer	Yes – pasture & buffer	(1 = yes)	0.69		0	1
	Sample size		2,106			

were male, and 88% were white. Average household size was six persons, with a minimum (maximum) of two (14). Home ownership (*own*), and if the respondent was a farmer or rancher (*farm*), were indicated with dummy variables. Eighty-nine percent of respondents were home-owners, and 27% were farmers or ranchers. The average distance from a respondent's household to the reservoir was 99 miles, with a minimum (maximum) of 1 (240) mile.

Respondent familiarity with the watershed was gauged with a Likert scale (average, 1.43; 1 = not at all familiar, 4 = very familiar), but 43% of the respondents indicated they used FCR for recreational activities. The average number of visits to the reservoir over the last 5 years was 1.31, with a minimum (maximum) number of visits of 0 (300). Respondents ranked water filtration (*benclean*, 45%) as the FCW's most important ecosystem service, followed by agriculture (*benag*, 25%), wildlife habitat (*benwild*, 18%), and erosion control (*benerode*, 10%).

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Respondent confidence that the survey would influence conservation legislation was 4.21 (*confidence*; scale, 0–10, with 10 "highly confident"). Respondents were also asked if they believed the hypothetical referendum would pass by a simple majority vote (*majority* = 1, 0 otherwise). Thirty-three percent of respondents believed the referendum would pass by majority vote.

A question was included in the survey to gauge respondent attentiveness (*attentive* = 1, 0 otherwise). Respondents were instructed to ignore a set of questions and instead click on a blue dot to advance to the next survey section. Fifty-seven percent of respondents correctly followed these instructions.

Respondents were asked a series of questions pertaining to issues facing policy-makers and Oklahoma's citizenry. The issues included (1) threats to security, including crime and terrorism; (2) concern of the cost and delivery of health care; (3) the availability and cost of energy; (4) the cost of transportation fuel including diesel and gasoline; (5) the cost of state and local taxes; (6) the cost and quality of education; (7) the state of Oklahoma's economy including jobs and inflation; and (8) natural resource conservation. "Concern" was measured on a 0 (not at all concerned) to 10 (most concerned) scale. Instead of including all eight variables directly in the estimation of WTP, the number of variables was reduced to two factors estimated with principal component analysis (Johnson and Wichern, 2002). The factor scores are standardized with a mean of zero and variance of one. Factor scores are uncorrelated, but each factor retains the set of information contained in variable groupings through their correlations. We named the first factor *costcommerce* because the variables loading into this factor were issues pertaining to activities supporting state commerce (issues 1, 3, 4, and 5). The second factor was named *costsocial* because the variables loading into it were related to cost associated with socioeconomic concerns (issues 2, 6, 7, and 8) (Table 1).

4.2 Hypothetical Referendum Supporting Best Management Practice Adoption

We used a one-shot, single binary discrete choice (SBDC) referendum format. This format is less likely to encourage strategic behavior than double-bound choice formats or open elicitation formats because it does not signal uncertainty with respect to the price of a hypothetical program (Arrow et al., 1993; Carson, Flores, and Meade, 2001). In addition to reducing strategic behavior, the SBDC referendum format is more realistic than other formats because it reduces the likelihood of hypothetical bias in CV contexts (Murphy et al., 2005).

The CV section of the survey introduced three hypothetical land use practices landowners or farm-ranch operators could adopt that would improve the watershed's water quality and reduce soil erosion; installation of riparian buffer strips and the conversion of cropland to pasture. Respondents were informed that these practices were used in some areas of the watershed, but adoption was low because of establishment and recurring costs. The hypothetical referendum context followed:

> *"Now we would like your input on a proposal to improve water quality in the Fort Cobb watershed. This proposal, called the Fort Cobb Watershed Water Quality Improvement Program, would go into effect if more than 50% of Oklahoma voters approve it in a statewide vote. Please consider the proposal carefully as your answers could be used to craft a future referendum or determine the amount of state funding allocated to this program."*

Program benefits were presented to respondents as a percent reduction in the frequency of algae blooms. Respondents viewed randomly one of four benefit levels of 25%, 50%, 75%, and 100% reduction in bloom frequency. This assignment was meant as an external scope test to evaluate consistency with economic theory (Kahneman,1986). In theory, respondents should be WTP more for a larger amount of the desired good (a higher percent reduction in algae blooms).

Next, respondents were randomly sorted into one of three tracks: *Increase Pasture Acres*, *Increase Riparian Buffer* area, and *Increase Pasture and Buffer Acres*. For each practice, respondents were instructed that farmer and rancher participation was voluntary, and that participating farms and ranches would receive cash incentives to implement the practice.

The referendum followed:

> *"The program would cost money to implement. The state government does not have the money to pay for the program, so the funding would come from a onetime only tax payment of $X per household. All of the tax money that is collected will be spent on increasing the amount of land in* ***[pasture, riparian buffer, or pasture and buffer]****"*

where $X is a one-time tax amount (t) randomly drawn from the dollar amounts of 2, 5, 10, 20, 30, 60, 90, 120, 150, 200, 250, and 500. Respondents were reminded that their vote ($yes = 1$, 0 otherwise) would only apply to producers in the FCW, and that if the referendum passed, they would be left with $X less to spend on other goods or services. After the yes/no vote, respondents were asked how likely policy-makers would use the survey results in their decisions to legislate water quality issues.

Sixty-two percent of the respondents voted "yes" in support of funding the conversion of cropland to pasture. The riparian buffer and pasture–riparian buffer programs were more popular, with "yes" votes of 68% and 69%, respectively (Table 1). There were 2,106 observations after removing records with missing information. Subsample sizes for the pasture, riparian buffer, and pasture and riparian buffer programs were 669, 717, and 717 records, respectively.

5. Methods and Procedures

An individual's WTP to support a program is the maximum amount of income (m) forgone for an improvement in reservoir water quality and FCW ecosystem services. We use a linear WTP function to estimate the dollar amount an individual would relinquish to support a cropland conversion and a riparian management program that encouraged farm and ranch owners to adopt pasture and stream bank BMPs (Habb and McConell, 2002). Let $v_{0i}(\mathbf{x}_i,\ m_i, \varepsilon_{0i})$ denote individual i's indirect utility, absent the BMP program. Individual characteristics including age, education, and other demographic variables enter $\mathbf{x}_i$ and were discussed above. The variable ε_{0i} a stochastic term with an expected value of zero and a constant variance. The indirect utility of an individual supporting the program is $v_{1i}(\mathbf{x}_i\ ,\ m_i - \mathrm{WTP}_i,\ \varepsilon_{1i})$. An individual is willing to pay to support the referendum when $v_{1i} > v_{0i}$. The stochastic terms are unobserved and the inequality favoring the referendum is only observable as a yes/no outcome (Hanemann, 1984).

McFadden (1973)'s random utility model is applied to parameterize indirect utility as a linear additive function of systematic and random components. Absent the BMP program, indirect utility is

$$v_{0i} = \mathbf{x}_i\boldsymbol{\alpha}_0 + \alpha_m \cdot m_i + \varepsilon_{0i} \tag{1}$$

where α_m is the marginal utility of income and $\boldsymbol{\alpha}_0$ are parameters. The indirect utility of an individual supporting the referendum is

$$v_{1i} = \mathbf{x}_i\boldsymbol{\alpha}_1 + \alpha_m \cdot (m_i - t_i) + \varepsilon_{1i} \tag{2}$$

where t_i is the dollar amount deducted from an individual's income to support the BMP program and the $\boldsymbol{\alpha}$'s are utility weights. The WTP argument appearing in the indirect utility function of an individual supporting the hypothetical referendum is replaced with a tax, t. In other words, the cost variable t is the point at which an individual is indifferent between supporting the hypothetical program or opposing it.

The difference between the indirect utilities under the status quo and supporting the program is a latent variable v^* observed as a probability, such that:

$$v_i^* = v_{1i} - v_{0i} = \mathbf{x}_i\boldsymbol{\alpha} - \alpha_m \cdot t_i + \varepsilon_i \tag{3}$$

where $\varepsilon_i = \varepsilon_{1i} - \varepsilon_{0i}$ is a random error with an expected value of zero and a constant variance σ^2, and $\boldsymbol{\alpha} = \boldsymbol{\alpha}_1 - \boldsymbol{\alpha}_0$. An individual is indifferent between the status quo state and supporting the program when v_i^* is zero. Setting $v_i^* = 0$ and solving for WTP, $WTP_i = \frac{\mathbf{x}_i\boldsymbol{\alpha}}{\alpha_m} + \frac{\varepsilon_i}{\alpha_m}$. The likelihood an individual supports the program at cost t_i is therefore:

$$\Pr\left[\mathrm{yes_i} = 1\right] = \Pr[\mathrm{WTP}_i > t_i] = \Pr[\varepsilon_i > \alpha_m \cdot t_i - \mathbf{x}_i\boldsymbol{\alpha}] \tag{4}$$

where "Pr" refers to probability.

The model is identified by normalizing the random component and other parameters by the error term's standard deviation (σ). The probability of observing a "yes" response becomes

$$\Pr[\mathrm{WTP}_i > t_i] = \Pr\left[\frac{\varepsilon_i}{\sigma} > \frac{\alpha_m}{\sigma} \cdot t_i - \mathbf{x}_i \frac{\boldsymbol{\alpha}}{\sigma}\right] = \mathcal{F}_\varepsilon[\varepsilon_i > \beta_m \cdot t_i + \mathbf{x}_i\boldsymbol{\beta}] \tag{5}$$

where $\mathcal{F}_\varepsilon$ is the error terms' symmetric cumulative distribution function (cdf) centered on zero at the median, with $\beta_m < 0$.

5.1 Bayesian Estimation of Beta-Binomial WTP

The logistic and standard normal cdf are natural choices for modeling binomial yes/no responses and are typically used to model the error distribution of equation (5). The tails of the logistic cdf are wider than the standard normal tails, which reduces the effects outliers may have on standard error estimates. A second issue related to thin-tail problems and outliers is overdispersion. Ignoring heterogeneity resulting from overdispersion causes omitted variable bias and compromises inference. If the unobserved process generating yes/no responses is a mixture of underlying processes other than the logistic distribution alone, then the variances of the expected probabilities may also be understated.

We use a beta-binomial mixture model to address these issues. The likelihood respondent i votes "yes" or "no" is

$$\Pr\left\{\mathrm{yes,\ no}\right\}_i \sim \mathrm{Beta}\left(p_i \cdot \theta,\ \left(1 - p_i\right) \cdot \theta\right) \tag{6}$$

with a dispersion parameter θ. Formulated this way, the response probability (p_i) for each respondent has its own distribution with the common scaling factor θ. Absent any information on individual preferences, $p_i = 0.5$, which means a respondent is equally likely to support or reject the hypothetical referendum. In this case, when $\theta = 2$, all probabilities on the (0, 1) line are equally likely because the distribution is Beta(1, 1) (the uniform distribution). As dispersion increases, respondent i's probability distribution masses over a single point and the tails thin. When $\theta < 2$, the probability distribution tends toward a bimodal u-shape with masses at zero and one. The parameter p_i is the logistic cdf, and is a function of respondent characteristics in $\mathbf{x}$:

$$\mathrm{logit}\left(p_i\right) = \beta_m \cdot t_i + \mathbf{x}_i\boldsymbol{\beta} \tag{7}$$

McElreath (2020)'s prior, $\theta = \phi + 2$, is used to parameterize the dispersion parameter. When dispersion is absent ($\phi = 0$) and a yes/no response is equally likely, then $\theta = 2$ and the prior probability of observing a "yes" vote is uniformly distributed on the (0,1) interval. The parameterization ensures that the lower bound of θ is two, indicating the absence of dispersion. A natural distribution for ϕ is the exponential, which has a minimum value of zero and preserves the flat, uniform prior when $\theta = 2$.

The beta-binomial parameters are estimated using Bayesian procedures. The posterior distributions of the model's parameters are recovered using R-Stan's Hamiltonian Monte

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Carlo No U-turn Sampler (HMC-NUTS) (Stan Development Team, 2020). The HMC-NUTS performance is superior to Gibbs or Metropolis–Hastings algorithms in terms of the number of iterations typically required for convergence (Hoffman and Gelman, 2011). The priors for equation (7)'s main effect parameters, and the parameter ϕ are

$$(\beta_m,\ \boldsymbol{\beta}) \sim \text{Student}-t_3(0,\ 2.5) \tag{8}$$

$$\phi \sim \text{Exponential}\ (1) \tag{9}$$

Set this way, the exponential scale prior carries no more information than an average deviation, which is the inverse of the rate parameter which is set to one (McElreath, 2020). The prior for $(\beta_m,\ \boldsymbol{\beta})$ are a centered Student t-distribution with three degrees of freedom and a standard deviation of 2.5. This prior typically exhibits better convergence properties compared to a normal prior (Bürkner, 2017). The tails of the Student t-distribution are wider than the normal's tails under similar variance assumptions and therefore accommodate potential outliers that could be drawn from the posterior distribution.

We ran one chain with a warm-up of 5,000 iterations with an additional 5,000 iterations to generate a set of posterior distributions. Every fifth sample was retained, resulting in 1,000 parameter samples. Chain convergence was verified using Gelman and Rubin (1992)'s diagnostic, $\hat{R}$. Diagnostics approaching one indicate that a parameter's chain is stationary and the model estimates converged.

5.2 Marginal Effects and WTP Premium

The marginal effects of covariates on the likelihood a respondent supports the hypothetical vote are calculated using the analytic forms of the logistic cdf (Wooldridge, 2010). For continuous covariates, the marginal effects are

$$\frac{\partial\,\Pr(''yes''\,|\,\mathbf{x})}{\partial x_k} = \beta_k \cdot \Pr\big(''\text{yes}''|\mathbf{x}\big)\cdot\big(1-\Pr\big(''\text{yes}''|\,\mathbf{x}\big)\big) \tag{10}$$

For (0, 1) covariates, the marginal effects are calculated as:

$$\frac{\Delta\,\Pr\big(''\text{yes}''\big)}{\Delta x_k} = \Pr\big(''\text{yes}''\,|\,\mathbf{x},\,x_k=1\big) - \ \Pr\big(''\text{yes}''\,|\,\mathbf{x},\,x_k=0\big) \tag{11}$$

The marginal effects were evaluated over the 1,000 posterior distributions for each record. We report the median, lower 2.5%, and upper 97.5% of the marginal effect distributions.

We evaluate WTP at the median (MD) of the error distribution using the posterior parameter estimates. Median WTP estimates are unbiased and unaffected by outliers (Habb and McConnel, 2002). At the error distribution's median $\varepsilon = 0$, and $MD(\text{WTP}) = -\frac{\mathbf{x}\beta}{\beta_m}$. The marginal change in WTP with respect to a one-unit change in a covariate is therefore,

$$\frac{\partial MD(\text{WTP})}{\partial x_k} = -\frac{\beta_k}{\beta_m} \tag{12}$$

We calculate WTP for every observation in the sample, evaluated with each posterior draw and resulting in 1,000 median WTP. The median, lower 2.5, and upper 97.5 percentiles of this distribution are reported. The WTP premiums associated with individual-specific characteristics are also evaluated at the median of the 1,000 draws from the posterior distributions.

5.3 Distribution-Free WTP

We also estimate WTP for the three BMPs using Turnbull (1976)'s distribution free WTP estimator as a robustness check. The Turnbull WTP estimator defines the lower and upper bounds of

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Table 2. Turnbull willingness-to-pay (WTP) estimates (dollars)

Cost ($)	Pasture			Riparian buffer			Pasture and Riparian buffer		
	No/yes	E(LB) [a]	E(UB)	No/yes	E(LB)	E(UB)	No/yes	E(LB)	E(UB)
2	10/50	0.17	0.42	7/58	0.06	0.15	3/52	0.15	0.36
5	14/42	0.17	0.33	10/58	0.39	1.56	10/65	0.2	0.79
10	17/43	0.26	0.53	8/55	(pooled)	(pooled)	6/45	(pooled)	(pooled)
20	20/42	1.19	3.58	14/51	2.12	3.18	10/50	2	3
30	15/36	(pooled)	pooled)	18/38	0.01	0.03	16/44	0.68	1.36
60	27/33	6.57	13.14	19/31	10.1	25.25	19/42	8.07	16.14
90	14/37	(pooled)	pooled)	16/37	(pooled)	(pooled)	16/44	(pooled)	(pooled)
120	34/37	4.11	5.14	21/50	(pooled)	(pooled)	27/31	1.65	2.75
150	23/21	5.68	18.93	29/25	0.24	0.4	23/37	(pooled)	(pooled)
200	30/25	(pooled)	(pooled)	21/27	(pooled)	(pooled)	28/36	10.91	13.64
250	25/28	(pooled)	(pooled)	30/31	28.56	57.13	31/32	45.17	90.33
500	27/22	224.49	673.47	40/26	196.97	590.91	37/18	163.64	490.91
Standard deviation		25.22			17.00			17.16	
Total WTP		242.64	715.87		238.46	678.82		232.46	619.39

[a]E(LB) and E(UB) are the WTP estimate's lower (LB) and upper bound (UB). The "no/yes" label indicates the number of respondents rejecting/accepting the bid. Numbers reported in the E(LB) and E(UB) columns are in dollars.

a range for median WTP (Habb and McConnell, 2002). The advantage of the Turnbull WTP estimator is that it is robust to functional form choice. A shortcoming of the Turnbull estimator is that the *ceteris paribus* effects of covariates on WTP cannot be assessed. Absent covariates, the parametric beta-binomial WTP estimators are expected to fall between the Turnbull lower and upper bounds.

6. Results and Discussion

Discussion of WTP and marginal effects focuses on the variable parameters that were significant at the 10% level or lower. The marginal effects of covariates on the likelihood of supporting the hypothetical referendum, and the effect of these covariates on WTP, are separately discussed for each practice.

6.1 Turnbull WTP Estimates

The lower (upper) Turnbull bounds for WTP to support the expansion of pasture acres were $243 (lower bound) ($716, upper bound) with a standard deviation of $25 (Table 2). Variability in the Turnbull WTP estimator was greater for the pasture expansion program than for the riparian buffer or pasture and riparian buffer programs. The lower (upper) bounds for supporting riparian buffer adoption were a one-time cost of $238 ($679), with a standard deviation of $17 (Table 2). The Turnbull WTP difference between the low and high bounds for the pasture and riparian buffer program was $387 (= $619 - $232), also with a standard deviation of $17 (Table 2). These findings are conservative bounds for the WTP estimates from the beta-binomial regressions. We expect the WTP estimates for each practice to fall within their respective Turnbull ranges.

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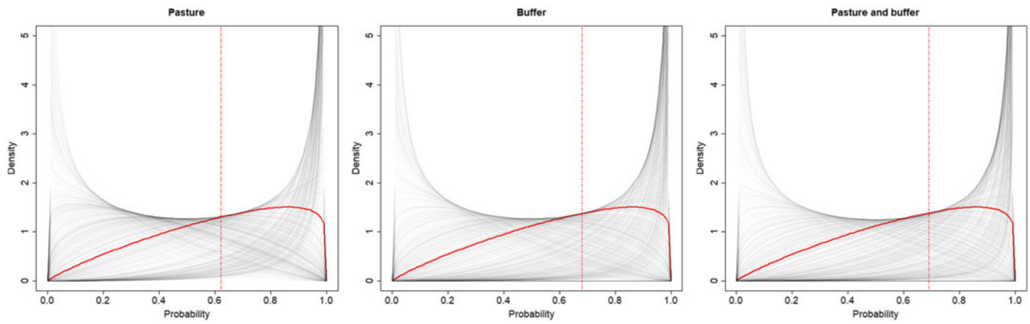

Figure 2. Probability distributions for willingness to support pasture, riparian buffers, and pasture–riparian buffer programs.
Note: Vertical lines are the means of the probability distributions.

6.2 Beta-Binomial Regression and WTP

Overdispersion occurs when the observed model variance is higher than the variance of the theoretical binomial-logistic model. Overdispersion is commonly observed in applied analyses because populations are frequently heterogeneous, which contradicts a key assumption of standard binomial logistic regression. The significance of the dispersion parameter suggests that WTP preferences to support producer adoption of the BMPs is heterogeneous among the sample of individuals randomly drawn from the Oklahoma's citizenry. The individual-specific probability distributions exhibit considerable heterogeneity for each regression (Figure 2). Averaged over the respondents, the predicted probability of a "yes" vote is, unsurprisingly, nearly identical to the sample averages of 62%, 68%, and 69% for the pasture, riparian buffer, and pasture and riparian buffer programs (dotted red lines, Figure 2). The scale parameters (ϕ) ranged from 0.68 to 0.72 (Table 3, which reports the margins), indicating divergence away from a uniform probability distribution and evidence the data were overdispersed.[2]

6.2.1 Cropland to Pasture Conversion

WTP for supporting the conversion of cropland to pasture was $257 (Table 4). One reason why WTP to support producer adoption of pasture improving practices was lower than the other programs could be that nonagricultural respondents perceive riparian buffers to be practices that are more effective in terms of soil conservation and water quality improvement.

Respondents who self-reported as *white* were 0.11 more likely to support the conversion of agricultural land to pasture relative to other groups (Table 3). Compared with other respondents, this group was willing to spend a one-time payment of $256 to support the conversion of row crops to pasture (Table 4).

The more confidence respondents had in the potential role of survey findings in influencing programming, the greater the probability individuals would vote "yes" to support all programs. A one-unit increase in the survey confidence scale corresponds with a 0.02 increase in the probability of voting "yes" to support the conversion of cropland to pasture (Table 3). The WTP premium for survey confidence was $47 for pasture expansion (Table 4). Respondents who believed that the hypothetical referendum would pass with a simple majority vote were 0.38 more likely to vote "yes" to support the pasture conversion program (Table 3).

[2]Adding "2" to these values, one arrives at the dispersion parameter θ.

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Table 3. Beta-binomial marginal effects for the probability of voting "yes"

Variable names	Pasture			Riparian buffer			Pasture & Riparian buffer		
	Median	L2.5[a]	L97.5[a]	Median	L2.5[a]	L97.5[a]	Median	L2.5[a]	L97.5[a]
age	−0.0007	−0.0033	0.0018	−−0.0004	−0.0025	0.0016	0.0005	−0.0020	0.0028
male	−0.0335	−0.0980	0.0397	−0.0264	−0.0833	0.0325	0.0353	−0.0272	0.0974
college	0.0042	−0.0621	0.0756	−0.0143	−0.0764	0.0470	−0.0240	−0.0882	0.0458
white	0.1097	0.0055	0.2057	0.0037	−0.0834	0.0965	0.0749	−0.0191	0.1744
hhsize	0.0014	−0.0065	0.0098	−0.0093	−0.0166	−0.0014	−0.0006	−0.0072	0.0075
own	−0.0190	−0.1295	0.0930	−0.0459	−0.1316	0.0529	−0.0089	−0.0980	0.0971
ranch	−0.0304	−0.1019	0.0450	0.0040	−0.0631	0.0761	−0.0106	−0.0802	0.0583
lakerecreate	−0.0519	−0.1195	0.0130	−0.0034	−0.0640	0.0584	0.0411	−0.0229	0.1004
resvisit	0.0016	−0.0050	0.0115	0.0069	0.0010	0.0150	0.0002	−0.0081	0.0088
familiar	0.0189	−0.0368	0.0731	0.0360	−0.0108	0.0851	0.0293	−0.0176	0.0753
algae	−0.0006	−0.0019	0.0005	−0.0003	−0.0013	0.0009	0.0001	−0.0009	0.0011
benclean	0.0015	−0.2463	0.2331	0.1350	−0.0622	0.2965	−0.0900	−0.2416	0.0991
benerode	−0.0393	−0.2982	0.1853	0.1261	−0.0744	0.2584	−0.0559	−0.2484	0.1338
benag	−0.0597	−0.2908	0.1704	0.0573	−0.1434	0.2121	−0.1628	−0.3501	0.0252
benwild	0.0480	−0.2045	0.2626	0.1000	−0.0918	0.2502	−0.0187	−0.2152	0.1554
costcommerce	−0.0123	−0.0469	0.0219	0.0526	0.0221	0.0816	−0.0245	−0.0544	0.0026
costsocial	−0.0069	−0.0372	0.0237	−0.0040	−0.0364	0.0286	0.0044	−0.0252	0.0334
confident	0.0197	0.0065	0.0319	0.0171	0.0055	0.0279	0.0236	0.0105	0.0352
majority	0.3769	0.3109	0.4398	0.3184	0.2553	0.3772	0.2774	0.2151	0.3383
attentive	−0.0540	−0.1222	0.0108	−0.0113	−0.0692	0.0491	−0.0164	−0.0741	0.0420
distance	−0.0003	−0.0009	0.0004	−0.0001	−0.0007	0.0005	−0.0007	−0.0012	−0.0001
cost	−0.0004	−0.0007	−0.0002	−0.0006	−0.0008	−0.0005	−0.0008	−0.0010	−0.0006
Intercept	0.7400	0.5250	0.9588	1.1771	0.9583	1.4385	1.1630	0.9409	1.4093
ϕ scale parameter	0.7174	0.0257	3.6553	0.6803	0.0243	3.3416	0.7254	0.0173	3.4434
Posterior log-likelihood		−417			−403			−403	
Sample size		669			717			717	

[a]L2.5 and L97.5 are the lower 2.5 and upper 97.5 percentiles of the marginal effect distributions, respectively. The intercept and scale parameters are posterior means of the regression.

6.2.2 Riparian Buffer Establishment

WTP to support the establishment of riparian buffers was $317 (Table 4). The WTP premium associated with this covariate (*revisit*) was $11 (Table 4). Respondents who believed the survey results would influence policy were 0.01 more likely to support the riparian buffer program (Table 3), which corresponds with a WTP premium of $26 (Table 4). Respondents were 0.26 more likely to support the riparian buffer program when they believed that the program supporting riparian buffer adoption by farm and ranch owners would pass. The premium associated with this variable was the largest among all other WTP premium at $519.

Household size was negatively correlated with the probability a respondent voted in favor of the riparian buffer program. A one-unit increase in the number of persons in a household was

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Table 4. Beta-binomial median willingness to pay for pasture and riparian buffer adoption (dollars)

Variable names	Pasture			Riparian buffer			Pasture and Riparian buffer		
	L05[a]	Median	U95	L05	Median	U95	L05	Median	U95
age	−9.04	−1.57	3.68	−3.67	−0.68	2.08	−2.05	0.57	3.19
male	−265.78	−78.60	66.90	−122.56	−39.64	40.10	−23.31	44.22	112.35
college	−127.97	9.53	174.90	−107.40	−23.07	57.90	−99.18	−29.11	44.31
white	53.48	255.59	625.38	−110.93	5.65	134.40	−4.92	91.27	201.24
hhsize	−13.33	3.60	24.00	−26.49	−14.46	−4.09	−8.16	−0.76	7.72
wwn	−318.59	−44.86	190.13	−213.85	−71.32	47.43	−112.56	−12.34	95.83
ranch	−266.39	−74.22	80.91	−87.37	6.12	102.80	−88.82	−13.24	66.97
lakerecreate	−349.73	−122.54	1.63	−82.94	−5.52	80.96	−12.45	53.03	123.57
resvisit	−10.52	3.84	25.86	2.94	10.83	22.20	−8.53	0.31	9.39
familiar	−75.59	45.90	179.80	−2.88	55.42	133.40	−13.70	37.93	87.90
algae	−5.25	−1.52	0.82	−1.82	−0.40	1.04	−0.95	0.13	1.25
benclean	−580.52	3.59	564.03	−50.09	212.02	484.26	−309.92	−117.80	90.55
benerode	−733.96	−91.71	503.62	−58.68	214.53	505.95	−278.62	−68.64	136.19
benag	−764.38	−135.45	395.53	−173.82	88.44	362.15	−426.12	−197.14	−4.38
benwild	−455.63	110.37	709.40	−100.08	165.38	460.97	−229.55	−24.42	192.97
costcommerce	−114.74	−30.21	41.58	41.20	81.26	130.42	−66.42	−31.31	−1.05
costsocial	−91.33	−17.04	47.05	−49.26	−6.65	33.72	−28.14	5.53	38.33
confident	18.73	46.60	104.24	10.99	26.31	44.93	16.04	29.86	45.65
majority	591.44	936.99	1886.65	365.96	519.31	758.20	268.91	383.08	545.07
attentive	−346.33	−131.43	0.82	−101.03	−17.48	64.37	−81.89	−20.78	41.64
distance	−2.42	−0.66	0.69	−0.94	−0.15	0.64	−1.61	−0.82	−0.23
WTP	174.89	256.92	423.91	254.99	316.62	397.68	242.91	290.33	355.97

[a]L05 and L95 are lower 5 and upper 95 percentiles of willingness to support distributions, respectively.

associated with a 0.01 decrease in the likelihood of supporting the riparian buffer program (Table 3). The same change in household size corresponded with a $15 decrease in WTP for the riparian buffer program (Table 4). Respondents who frequently visited the FCR were more likely to support the riparian buffer program. A respondent was 0.01 more likely to support the riparian buffer program for each additional recreational visit to the reservoir between 2010 and 2015 (Table 3).

6.2.3 Cropland to Pasture Conversion and Riparian Buffer Establishment

WTP to support both the conversion of cropland to pasture and the establishment of riparian buffers was $290 (Table 4). The pasture and riparian buffer WTP premium for survey confidence was $30 (Table 4). Respondents who believed that a pasture and riparian buffer program would pass by a majority vote attributed a $383 premium to this program (Table 4). These individuals were also 0.22 more likely to vote “yes” to support pasture conversion and riparian buffer adoption.

Respondent proximity to the FCR was negatively associated with the likelihood of supporting the pasture–riparian buffer program. For an additional 100 miles distance between the respondent's household and the watershed, the likelihood of voting "yes" to support the pasture–riparian buffer program decreased by 0.02 (Table 3). The WTP premium on proximity to FCR was -$8.20 for a 10-mile increase in distance to the site (Table 4). Respondent confidence in the survey with respect to influencing policy was positively associated with the probability of supporting the pasture and riparian buffer program. A 1-unit increase in survey confidence increased the likelihood of supporting this combined program by 0.01 (Table 3).

7. Conclusions

Previous literature on the voluntary use of BMPs typically focuses on the producer's adoption decision to practices. This study examined adoption from the perspective of the citizens and their WTP for farmer adoption of BMPs. The study used Oklahoma's M-SISNet survey, a representative panel survey of Oklahoma's citizens. The M-SISNet Wave 7 survey included a hypothetical, referendum-style CV section. The hypothetical referendum asked citizens if they would vote for a one-time tax to support farmer conversion of cropland to pasture and to install riparian buffers. Oklahoma's FCR and its headwaters was the watershed where the hypothetical program would be implemented. The FCR and its tributaries are listed as impaired due to agricultural runoff. Understanding Oklahoma citizens' perceptions on the existence and use value of the FCR could inform watershed managers and legislators about the public's enthusiasm to support financially programs encouraging the voluntary adoption of BMPs by agricultural producers.

Respondent reasons for supporting the hypothetical programs included a desire for a cleaner reservoir, reduction in soil erosion, support for agricultural operators, and enhancement of wildlife habitat. People familiar with the watershed would likely support all three programs and favor the riparian buffer and combined pasture and riparian buffer programs. Respondents who owned or operated a farm or ranch, and who visited frequently the FCR, were more likely to support riparian buffer program. Ranchers and frequent FCR visitors were less likely to support the combined pasture and riparian buffer program.

The hypothetical program suggests that a majority of Oklahoma's citizens would support a one-time payment supporting farmer adoption of these land management practices. Technical and financial support of adoption of BMPs is a cost-effective approach toward mitigating soil erosion and enhancing water quality in the FCW. The findings suggest a win-win scenario for both agricultural producers and those benefiting directly and indirectly from the FCR's ecosystem services.

The CV analysis found citizen WTP for programs sponsoring the conversion of cropland to pasture and the installation of riparian buffers. WTP was highest for a program funding the installation of riparian buffers ($317), followed by a program supporting riparian buffer installation and conversion of cropland to pasture ($290). WTP for conversion of cropland to pasture was $257. Depending on the practice considered, the percent of respondents voting "yes" to support the referendum ranged between 68% and 73%. The WTP also varied according to respondent characteristics, belief in the study's potential to affect legislation, and belief that a majority of residents would in fact vote "yes" on the referendum.

A limitation of this study is that the survey only considered a one-time tax as a funding source for supporting Fort Cobb's watershed and water quality restoration. Adoption is a one-time event, but continued use of an adopted practice may require additional incentives. If installation of riparian buffers includes fencing or stream crossings for livestock, then the annual maintenance costs of these structures might be a disincentive to adopt a BMP. The second limitation of this study is the lack of specificity with respect to program components. Conversion of cropland to pasture and installation of riparian buffers may require bundles of components and technical

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assistance, as evidenced by EQIP and CSP program details. This limitation would be of greater concern if the survey focused on willingness-to-adopt from the producer's vantage. Agricultural producers are aware of the opportunity costs BMP programs bring with them. Citizens, on the other hand, would likely be less informed about the time and effort needed to implement these BMPs and consequently less interested in the hypothetical program's details.

Another limitation of this study is that the survey did not include follow-up questions on why a respondent chose to support, or not support, the referendum. This limitation cannot be addressed with the available data. Future surveys should include debriefing questions to elucidate further reasons why individuals support, or oppose, hypothetical programs such as those considered here.

In line with past work, the results indicate that the respondents were generally insensitive to scope, as evidenced by the insignificance of the *algae* variable (Kahneman, 1986; Kahneman and Knetsch, 1992). We postulate that the primary reason for this is that the benefit levels were insufficiently emphasized. The reduction level was one number in a paragraph of text that included the cost of the program, so respondents may have overlooked it when focusing on the details and cost of the program. Future survey work in this area should emphasize this aspect.

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Competing Interest. The authors declare that there is no conflict of interest.

Data Availability Statement. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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