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The Economic Value of Water Quality

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Abstract Stated preference values for water quality ratings based on the US Environmental Protection Agency National Water Quality Inventory ratings provide an operational basis for benefit assessment. Iterative choice survey results for a very large, nationally representative, Web-based panel imply an average valuation of $32 for each percent increase in lakes and rivers in the region for which water quality is rated "Good." Valuations are skewed, with the mean value more than double the median. Sources of heterogeneity in benefit values include differences in responses to average water quality information and the base level of water quality. Conjoint estimates are somewhat lower than the iterative choice values. The annual economic value of the decline in inland US water quality from 1994 to 2000 is over $20 billion.

Keywords Water quality · Stated preference · Conjoint analysis

JEL Classification Q25 · Q26

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[1] Over the past quarter century, all proposed major new US regulations have been subject to a requirement that benefits and costs be quantified and that the agency show that the benefits exceed the costs. This requirement is binding provided that meeting the test does not conflict with the agency's legislative mandate. The following executive orders have governed this policy: E.O. 12291, E.O.12866, and E.O. 13528.

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1 Introduction

The monetization of the benefits of water quality improvements is a central component of evaluating the cost-benefit performance of water quality regulations.[1] All major regulations in the US must be accompanied by a regulatory analysis that calculates the benefits and costs of the regulations and, unless prohibited by the legislative mandate for the particular policy, the agency must demonstrate that the economic benefits exceed the costs. In addition, economic assessment of the benefits of environmental policies is often a major component of their assessment of the performance of existing regulations. This study reports on research that was undertaken for the US Environmental Protection Agency (EPA) to provide the basis for that agency's assessment of these water quality benefits. Although the role of benefit-cost analysis of water quality policies is not as strong in the EU as it is in the US, benefit assessment for water quality policies is a major consideration in policy evaluation.[2]

While the economic principle of measuring benefits based on society's willingness to pay for water quality is quite general, implementing this principle in a policy relevant manner requires that one account for the structure of the water quality measures to be valued. The EPA currently constructs measures of water quality based on whether water quality is rated "Good" on a variety of dimensions, including fishing, swimming, and the aquatic environment.[3] This paper develops survey-based estimates of water quality benefits using a metric based on the EPA water quality index and applies these estimates to value water quality changes in the US from 1994 to 2000. Our approach has broader implications for the valuation of water quality generally, as the European Union (EU) Water Framework Directive uses a similar approach in its definition of protected areas as well as "Good" status for water bodies in its policy goals.[4] As will be discussed below, the US EPA definition of "Good" is more closely tied to end uses of water rather than the biological and physio-chemical characteristics that play a more central role in the EU ratings, and as a result can be more readily linked to a stated preference benefits assessment task.

The basic survey structure uses a stated preference approach. Respondents considered a series of iterative paired comparisons, building on the method used to value water quality in Magat et al. (2000).[5] This article extends that earlier pilot study in several ways. Magat et al. used a convenience sample of 348 respondents collected using central location and mall intercept modes in North Carolina and Colorado, whereas the sample for this study is much larger (4,033 respondents) and was drawn from a nationally representative, Web-based panel. The part of the survey using a series of iterative paired comparisons is greatly expanded to include the analysis of external water quality reference points, base rate effects, and the nature of the choices considered. In addition, a separate conjoint analysis provides an alternative, different perspective on water quality-money-tradeoff rates. The expanded

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[2] For example, Sect. 3 of Article 174 of the European Union Treaty states: "In preparing its policy on the environment, the Community shall take account of: available scientific and technical data, environmental conditions in the various regions of the Community, the potential benefits and costs of action or lack of action, the economic and social development of the Community as a whole and the balanced development of its regions." Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 offers the general guidance: "Pursuant to Article 174 of the Treaty, in preparing its policy on the environment, the Community is to take account of available scientific and technical data, environmental conditions in the various regions of the Community, and the economic and social development of the Community as a whole and the balanced development of its regions as well as the potential benefits and costs of action or lack of action."

[3] See the US Environmental Protection Agency (1994) for a description of these data.

[4] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000.

[5] See also DeShazo (2002), and more generally, Louviere (1988) and Louviere et al. (2000) for analysis of stated preference approaches.

survey structure, which is described in Sect. 2, makes possible a determination for each respondent of the tradeoff between cost of living and water quality, thus providing information on the heterogeneity of water quality benefits across the population. This information is consequently much richer than would be derived from a survey approach to elicit the average valuation across the population.

The empirical exploration of these results in Sect. 3 considers the influence of demographic factors and other determinants of water quality values. Included in this exploration is an examination of the rationality of the responses, as reflected in a series of across person scope tests. To minimize the influence of anchoring effects, the article also proposes that using the survey results based on a 50–50 split in the initial paired comparison choice yields results that we refer to as "equitable tradeoffs." The result of using this tradeoff is that a unit increase in the percentage of lakes and rivers rated "Good" has a mean value of \$32 and a median value of \$13. Because valuations are on an individual respondent basis, the analysis provides information on the entire distribution.

As an additional validation of the methodology, Sect. 4 presents the water quality benefit estimates based on a simpler conjoint approach.[6] That survey structure yields water quality benefits values similar to those derived from the stated preference responses, and also establishes the relative value of improvements in lakes versus rivers.

Using the water quality benefit values and the lake-river relative benefit weights, Sect. 5 estimates the economic cost of the water quality deterioration between 1994 and 2000. This loss, which imposes an annual economic loss in excess of \$21.8 billion, highlights the importance of water quality within environmental policy generally. Section 6 concludes.

2 The Survey Approach

2.1 Defining Water Quality for Respondents

Both the US EPA and the EU Water Framework Directive define water quality using gradations. The EPA water quality hierarchy is good (fully supporting), good (threatened), impaired, and not attainable, while EU's Water Framework Directive uses water quality rated high, good, moderate, poor, and bad. Within each of these qualitative ratings, there are some differences between the US and EU definitions. As indicated below, the US EPA definition of "Good" is strongly but not exclusively oriented toward end uses, in particular whether the water is safe for swimming, will support fish that are safe to eat, and will support plants, fish, and other aquatic life. To the extent that the chemical and biological characteristics of the water enter, it is as an input to determining whether any of these dimensions are threatened rather than as an independent matter of interest. The EU Water Framework Directive for surface water rated as having "Good status" emphasizes that there be "low levels of distortion resulting from human activity" and that it meet specific criteria for biological quality elements (phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna, and fish fauna), hydromorphological quality elements (hydrological regime, river continuity, and morphological conditions), and physico-chemical quality elements (general conditions, specific synthetic pollutants, and specific non-synthetic pollutants).[7] These types of considerations are not specific ratings endpoints of the US water quality ratings, which instead are more closely linked to operational economic benefit components. However, in each case the

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[6] The first use of the conjoint methodology in the environmental economics literature is Magat et al. (1988).

[7] See Table 1.2 of Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000.

"Good status" rating for surface water is structured to ensure that water quality is viable for fishing, swimming, and aquatic uses so that there are substantial commonalities in the two rating schemes' designation of what constitutes Good water quality. The primary emphasis is on whether water is suitable for recreational purposes.

When addressing policy objectives, both systems mandate that water quality achieve at least a rating of "Good." Whether water quality is rated "Good" is also the primary emphasis of US water quality data and policy evaluations. The survey therefore uses a dichotomous rating of whether water quality is rated "Good." This formulation not only enables the results to be used in conjunction with existing data on water quality levels,[8] but also captures the discrete nature of many water quality attributes, such as whether the water is safe for swimming or fishing. The survey structure consequently obtains average values for water quality levels above and below the Good/Not Good cutoff. Other portions of the survey described below explore values when water quality is Good on some dimensions but not others. The general strategy of the survey was to minimize both the number of categories and the complexity of the tradeoff, to enable respondents to successfully complete the task.

2.2 Survey Structure

The survey used a computer-based methodology administered to a representative national sample. The main survey tasks involved a series of pairwise choice questions and conjoint valuations. Before considering these tradeoffs, the respondents first were asked to think about their use of water by completing a series of tasks that elicited information about their usage of freshwater bodies and related activities, such as boating, fishing, and swimming. The survey then explained the meaning of cost of living and encouraged them to think about how much their lives might change given an increase in the cost of living.

The next component of the survey defined "Good" water quality based on the definitions used by EPA's National Water Quality Inventory:

> The government rates water quality as either
> ∗ Good, or
> ∗ Not Good.
> Water quality is Good if water in a lake or river is safe for all uses.
> Water quality is Not Good if a lake or river is polluted or unsafe to use.
> More specifically, water quality is Not Good if the lake or river
> ∗ Is an unsafe place to swim due to pollution,
> ∗ Has fish that are unsafe to eat, or
> ∗ Supports only a small number of plants, fish, and other aquatic life.

The survey explicitly excluded drinking water from the valuation task.

In addition to general background information on water quality, half the respondents received information about the percentage of water in the country that is rated "Good." This value, which was 65%, was intended to assist respondents in putting the survey figures in context.[9] Respondents may have a distinct valuation of water quality relative to the national average that is a legitimate reflection of their underlying preferences in much the same way that people may care about their relative economic status. Thus, to the extent that people used the national value as the target for what water quality level is appropriate for their region, receiving the national information was expected to boost water quality benefit values for base

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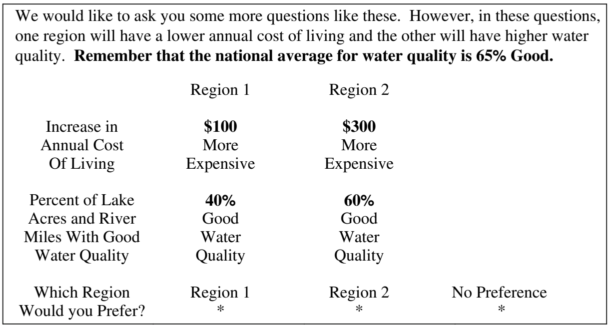
[8] See US EPA (1994–2002).

[9] According to the National Water Quality Inventory Reports to Congress, these numbers were 64% of rivers and 63% of lakes in 1994, 64%/61% in 1991, 65%/55% in 1998, and 61%/54% in 2000.



We would like to ask you some more questions like these. However, in these questions, one region will have a lower annual cost of living and the other will have higher water quality. **Remember that the national average for water quality is 65% Good.**

	Region 1	Region 2	
Increase in Annual Cost Of Living	**$100** More Expensive	**$300** More Expensive	
Percent of Lake Acres and River Miles With Good Water Quality	**40%** Good Water Quality	**60%** Good Water Quality	
Which Region Would you Prefer?	Region 1 *	Region 2 *	No Preference *

Fig. 1 Sample regional water quality benefit question

water quality levels below this value and decrease valuations if the base water quality already exceeds the national average. We will show that people who are told their new region has lower quality than the national average place a higher value on improvements than those told they are moving to a region that is better than the nation overall.

The survey defined relevant water quality as residing in a region that is “a 2-hour drive or so of your home, in other words, within 100 miles.” About 80% of all recreational uses of bodies of water are within such a radius of users’ homes.[10]

The stated preference question set began with a choice to move to one of two regions that differed on two dimensions—cost of living and the percentage of water in the region rated “Good.” The regions are “the same in all other ways, including the number of lakes and rivers near your home.” Figure 1 provides an example of a regional water quality choice question. The choice was framed with respect to a new region to ensure stable valuations, because otherwise respondents might use particular knowledge they may have about local water quality and ignore the water quality levels presented in questions. Extensive cognitive interviews and pretesting of this survey indicated that respondents were not adversely affected by the hypothetical move structure. Previous research has found that this regional choice task yields values corroborated by implicit values from market-based evidence,[11] and results from this survey also suggest that respondents responded appropriately to the question. We find that geographic variables and state water quality level variables that are not relevant given that it is a new region, did not have a significant effect on valuations. By contrast, the density of water in the state, which the survey indicated would also characterize the new region did have a significant effect on water quality valuations.

The use of starting values potentially could produce anchoring effects, as the literature documents that starting point effects generally do.[12] The survey used a broad range of 13 different combinations of initial cost of living and water quality for different respondents.[13]

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[10] Data generated by the EPA NCEE Office for this study indicate that 77.9% of boating visits, 78.1% of fishing visits, and 76.9% of swimming recreational visits are within a 100 mile radius. Calculations were made by Jared Creason of NCEE using the 1996 National Survey on Recreation and the Environment.

[11] See Viscusi et al. (1991) for regional choice tradeoffs involving auto fatality risks and cost of living, where these results parallel the hedonic price literature findings for the value of statistical life.

[12] See, for example, Rowe et al. (1980) and Boyle et al. (1985).

[13] There are four starting cost differences ($200, $300, $400, $500) and six starting quality differences (10%, 15%, 20%, 25%, 30%, 40%). These produce 13 starting cost/quality pairings: $200 × (10%, 20%, 40%), $300 × (10%, 15%, 20%, 30%), $400 × (15%, 20%, 25%, 40%), $500 × (20%, 25%). As a result, there are eight starting ratios of cost differences/water quality differences: (5, 10, 15, 16, 20, 25, 26.67, 30).

Below we explore the influence of possible anchoring effects of the starting choice and propose a solution to such effects. Because of the potential importance of anchoring effects, in a separate paper we examine such influences in detail.[14]

The choice shown in Fig. 1 pits a low cost, low water quality region 1 and the high cost, high water quality region 2. More specifically, if we let c_i be the cost of living in region $i, i = 1, 2$; and let g_i be the percent of water in region i rated "Good," then the value v of water quality benefits is the tradeoff rate between cost of living and the percent of water rated "Good" and is given by

$$\nu = (c_2 - c_1) / (g_2 - g_1) . \tag{1}$$

If a respondent expresses indifference to the choice in Fig. 1, the implied water quality value is \$10 per 1 point change in percent of water rated "Good" (\$300 − \$100)/(60% − 40%) = \$10/percent water quality rated "Good."[15] Respondents who choose region 1 reveal a valuation of under \$10 per unit of water quality, and respondents who choose region 2 reveal a value above \$10. Just how much these individuals differ from \$10 is determined through a subsequent series of tradeoffs.

Respondents considered a series of up to five iterative choices that continued until they reach a point of indifference, reverse their preference between regions 1 and 2, or they reach a corner on the decision tree. Figure 2 provides an example of this structure for the choice task in Fig. 1. Respondents who initially indicate a preference for the high water quality region 2 face choices with successively lower water quality values, while those who prefer the low cost of living in region 1 face choices with successively higher cost of living values. As is indicated by the decision tree, this process continues until respondents either switch their regional choice, thus bounding their valuation,[16] or they reach a corner, where they face a dominated choice. The iterative choice questions consequently serve to engage respondents by starting them with a simple choice, then narrowing that choice to more difficult tradeoffs until a closely bounded value is determined. This path of simple to difficult was an effective method of getting thoughtful values for a non-market good. The survey also includes additional survey questions to measure water quality values (conjoint questions), which result in estimates quite similar to the iterative choice set.[17]

Respondents who chose a dominated choice in the iterative choice set despite a reminder that it is dominated, are labeled "inconsistent," and those who reach the corners but do not choose a dominated option reflect upper or lower bounded censored responses.[18] Thus, for the survey structure in Fig. 2, respondents who consistently indicate a preference for water quality region 2 fail the dominance test if they prefer region 2 when it offers the (cost of living, water quality) pair of (\$300, 40%) as compared to (\$100, 40%) in region 1. Similarly, respondents who consistently prefer region 1 fail the test if they prefer (\$300, 40%) in region

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[14] See Huber et al. (2007). Our proposed solution to the influence of anchoring is that the initial response should reflect a 50–50 split between the pro-environment and low cost alternatives. For other approaches to
Footnote 14 continued
anchoring effects and starting point biases see, among others, Herriges and Shogren (1996) and Frykblom and Shogren (2000).

[15] Overall, 6.8% of respondents indicated no preference for the first tradeoff choice. If those respondents are excluded, the estimated value of water quality is about 8% higher than if they are included.

[16] Subjects who switch from the higher environmental quality region to the lower cost region received tradeoff values equal to the midpoint of the range bounded by those two sets of choices.

[17] Also, for the logit equation presented in Table 1, a tradeoff can be calculated using only one question, and this value is less than 4% different than the median of the full question set.

[18] The 5% of observations that are inconsistent are excluded from the empirical analysis.

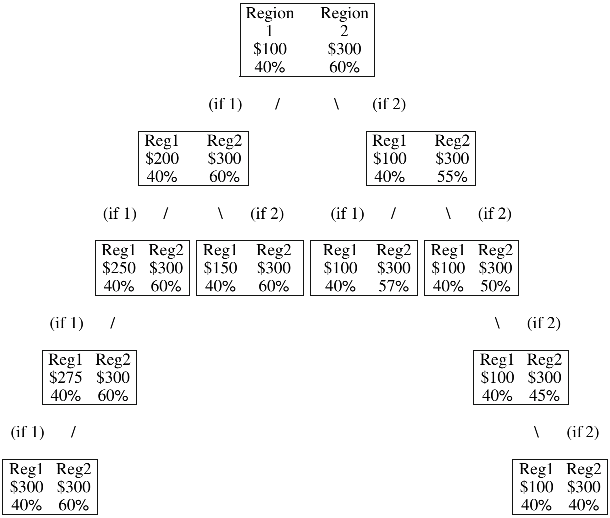

Fig. 2 Survey decision tree

Table 1 Two-limit censored regression of log unit of value of water quality benefits[a]

Variable	Parameter estimate	Standard error
Log (income)	0.1171*	0.0230
Years of education	0.0369*	0.0080
Age	0.0063*	0.0012
Environmental organization membership	0.4659*	0.0885
Visits to lakes or rivers, last 12 months	0.0316*	0.0061
Visits, outside region, last 12 months	0.0728*	0.0200
Race: black	−0.0979	0.0597
Race: non-black, non-white	0.0322	0.0820
Hispanic	0.1279**	0.0655
Gender: female	−0.0379	0.0391
Household size	−0.0285**	0.0153
Region: Northeast	0.0629	0.0610
Region: South	−0.0012	0.0555
Region: West	0.0090	0.0605
State lake quality	0.0004	0.0008
Lake acres per State square mile	0.0036**	0.0021
Respondent told national quality level (zero centered)	−0.0386	0.0390
Log (base water quality level) (zero centered)	−0.4392*	0.0915
Told (zero centered) × log (base quality) (zero centered)	−0.4455*	0.1559
Log (starting water quality tradeoff) (zero centered)	0.5232*	0.0636
Intercept	0.4748**	0.2551
Pseudo R-Squared: 0.0267		

[a] *Notes*: *significant at .01 level, **significant at .10 level, both two-tailed tests. Results are for the consistent sample of 4,033, including 376 left censored and 403 right censored observations

1 to (\$300, 60%) in region 2. Thus, in addition to undertaking standard scope tests, the survey methodology incorporates a dominance test for the rationality of responses, which 95% of all respondents passed.

Of those respondents remaining, 19% of all responses were unbounded from above or below and thus were treated as censored. Specifically, 376 respondents out of 4,033 were left censored, indicating a continuing preference for the low cost-low water quality region 1, and 403 were right censored, favoring the high cost-high water quality region 2. Estimates for these respondents are provided by a censored regression based on the assumption that their valuation takes a log-normal distribution and that they are influenced by the independent variables in the same way as the unbounded respondents.

2.3 The Sample

The sample for this study is from the Knowledge Networks (KN) Web-based panel. A pilot survey, a series of pretests, cognitive interviews, and focus groups preceded the development of the final survey instrument, which is the focus of this paper. The KN panel is representative of the United States' adult population, having been built from a probability random digit dialing approach. KN offered members of the panel an incentive payment of \$10 to take the survey, which the average respondent took about 25 min to complete. Most of the surveys were administered between late April and early October 2004. The response rate was 75%, and there are 4,527 completed surveys in the sample.[19] Table 2 compares the distribution of sample characteristics with that of the US population, indicating close parallels. There is an excellent representation of minorities in the survey and a slight under sampling of low-income groups. The sample has somewhat fewer college graduates and above than does the national population, which is the opposite of the sampling problem expected with a computer-based sample. Overall, there is a superb match-up of the survey participants with the national demographic statistics.

2.4 Scope Tests

A basic rationality requirement for the survey structure in Fig. 1 is that respondents should respond to cost differences and quality differences in the expected economic manner. If respondents are merely expressing approval for environmental qualities rather than expressing rational values for particular levels, their valuations will fail a scope test.[20] To explore whether valuations of changes in starting cost and water quality pass this test, Table 3 presents logit regression results for whether the respondent chose the higher cost, higher water quality region. The first explanatory variable $c_2 - c_1$ has the expected negative effect, as increasing the cost premium decreases the probability of choosing the high cost region. Similarly, raising the value of water quality difference $g_2 - g_1$ increases the value of the higher water quality region as reflected in the statistically significant effect of this variable. These responses to changes in the environmental good consequently pass an across-subjects scope test.[21]

This basic scope test can be augmented by the more extensive tests developed by Heberlein et al. (2005): affective, cognitive, and behavioral scope tests. Positive affective scope requires

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[19] The final sample of 4,033 is due to the exclusion of inconsistent respondents, respondents who did not answer all of the questions in the iterated question set, and a small number of respondents with missing data for demographic variables used in the analyses.

[20] For discussion of such embedding effects, see Kahneman and Knetsch (1992).

[21] See also Heberlein et al. (2005) and Smith and Osborne (1996) for discussion of the merits and limitations of scope tests.

Table 2 Comparison of KN sample to the national adult population[a]

Demographic variable	Survey participants (%)	US adult population (%)
Employment status (16 years or older)		
Employed	61.3	62.3
Age		
18–24 years old	13.4	13.3
25–34 years old	20.1	18.3
35–44 years old	19.4	20.4
45–54 years old	18.6	18.7
55–64 years old	11.9	12.2
65–74 years old	11.7	8.4
75 years old or older	4.9	8.1
Educational attainment		
Less than high school (HS)	18.5	15.4
HS diploma or higher	59.4	57.4
Bachelor or higher	22.2	27.2
Race/ethnicity		
White	80.3	81.9
Black/African-American	13.3	11.8
American Indian or Alaska Native	1.6	0.9
Asian/Pacific Islander/other	4.8	5.5
Race/ethnicity of household		
Hispanic	10.6	12.1
Gender		
Male	51.0	48.5
Female	49.0	51.5
Marital status		
Married	58.4	58.8
Single (never married)	25.6	24.4
Divorced	10.9	10.2
Widowed	5.1	6.6
Household income (2002)		
Less than \$15,000	15.0	16.1
\$15,000–\$24,999	11.6	13.2
\$25,000–\$34,999	12.5	12.3
\$35,000–\$49,999	18.8	15.1
\$50,000–\$74,999	18.2	18.3
\$75,000 or more	23.8	25.1

[a] Statistical abstract of the United States, 2004–2005. 2003 adult population (18 years+), unless otherwise noted. $N = 4{,}257$

that people who like environmental amenities more on the whole should have higher values than those who do not. Cognitive scope requires that those who think more about the good should have higher values of the good. Behavioral scope requires that those who use the resource should value it more highly.

Table 3 Scope test, logit regression of initial respondent choice of higher cost, higher quality region[a]

Variable	Parameter estimate	Asymptotic standard error
Cost difference in first question, $c_2 - c_1$	−0.0025*	0.0004
Quality difference in first question, $g_2 - g_1$	0.0357*	0.0045
Intercept	−0.0109	0.1302

[a] *Notes*: *significant at the .01 level, two-tailed test. $N = 3{,}757$

We test affective scope by comparing the valuations of respondents who are members of environmental organizations with those who are not. Overall, environmental group members have water quality valuations that have mean values of $35.53 as compared to $22.28 for non-environmentalists, or 59.5% higher ($t = 8.2$). These results are consistent with the presence of affective scope.[22]

Positive cognitive scope requires that those who think about the good more often should have higher values for the good. We found that if the respondent viewed lakes and rivers often over the past 12 months that their mean valuations of water quality were $25.27, while those who did not view lakes and rivers often had 18.0% lower valuations of $20.73 for water quality ($t = 6.2$). These results as well as the aforementioned environmental group member results are consistent with the presence of affective scope with respect to the water quality values.

Finally, positive behavioral scope requires that those who use the resource more should have higher values for the resource. The water quality valuations increase as the respondent's level of usage of lakes and rivers during the past 12 months rises. Those who have taken some trips but none outside of their home region have valuations of $22.64 that are 10.3% higher than the $20.52 value for those who took no trips ($t = 2.4$). Similarly, those who made trips to lakes and rivers both in their region and out of their region had values of $25.92 that are 14.5% higher than the value of $22.64 for those who only took trips within their region ($t = 3.6$) and 26.3% higher than the $20.52 value for those who made no trips to lakes or rivers ($t = 5.9$). Behavioral factors are not only pertinent to the behavioral scope tests but also will play a role in the regression results presented below.

3 Stated Preference Regression Results

3.1 Censored Regression Estimates

To explore the valuation of water quality and the determinants of those values, we analyze the 4,033 respondents who did not choose a dominated regional choice option.[23] The dependent variable in our analysis is $\ln(v)$, where v is the water quality value at the point of indifference for respondents who reached indifference or the midpoint value between the successive final choices. The doubly censored regression takes the following form. Let $\underline{v}$ be the lower bound

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[22] The differences and t-values reported here and for the other scope tests use the raw survey values, not the estimated values produced by the censored regression analysis. However, these differences are significant in regression models as well.

[23] Overall, there were 214 subjects who exhibited such an inconsistency. Including the inconsistent responses in the regression as censored observations at the point on their decision tree where they exhibited intransitivity yields very similar results.

value permitted by the iterative choice structure given to the particular respondent, and let $\overline{v}$ be the upper bound value permitted. For the example shown in Fig. 2, the value of $\underline{v}$ is \$1.25, i.e., $(\$300-\$275)/(60\%-40\%)$, and the value of $\overline{v}$ is \$40, i.e., $(\$300-\$100)/(45\%-40\%)$.

If we let the log of the respondent's valuation of water quality be given by $\ln(v^*)$, the explanatory variable vector be x, and the coefficient vector be β, the model of the survey responses takes the form

$$\ln(v^*) = x'\beta + \varepsilon, \tag{2}$$

where

$$\ln(v) = \ln(\underline{v}) \quad \text{if } v^* \leq \underline{v}, \tag{3}$$

$$\ln(v) = \ln(v*) \quad \text{if } \underline{v} < v^* < \overline{v}, \tag{4}$$

and

$$\ln(v) = \ln(\overline{v}) \quad \text{if } v^* \geq \overline{v}, \tag{5}$$

where the value of $\varepsilon_i \,|x_i$ is assumed approximately Normal (0, σ^2). The log-likelihood consequently is the sum of terms for each of these three regions, and the maximum likelihood estimates follow a standard two-limit censored normal regression approach. In terms of the distribution of responses, there are 376 left censored respondents with values censored at the floor amounts permitted by their survey, 403 right censored observations who hit the permissible upper limit, and 3,254 interior values in which a tradeoff rate is observed. The censored regression estimates in Table 1 report results for the natural log of v* as the dependent variable.[24]

The statistically significant demographic variables are consistent with the usual economic hypotheses. There is an appropriate positive income elasticity for the value of clean water. Additionally we find a positive effect of additional years of education, which is reasonable given that education is correlated with lifetime wealth. There is a negative effect for large households, which is consistent with their lower per capita wealth. Finally, there is a positive effect of respondent age.

As mentioned in the discussion of scope, several environmental-related variables are influential as well. Respondents who are members of an environmental organization exhibit higher benefit values, as one would expect based on affective scope.[25] Similarly, for respondents in states where there is a high density of lakes, the benefit values are higher. While the survey indicated that the water quality levels in the new region in the stated preference choice would differ from their current region, the density of lakes and rivers would remain the same. Consequently, the effect of lake density could reflect either the sorting of people with high benefit values into such states, as in the standard Tiebout model, or the greater benefit of a percentage gain in water quality when there are a large number of lakes.

People who use water bodies should exhibit higher values than those for whom there is only passive benefit. These water quality usage effects can be used to estimate how water

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[24] We also performed quantile regressions for the 25% quantile, median, and 75% quantile. Results were stable across the quantiles with significant coefficients holding the same signs through all quantiles.

[25] The particular environmental organizations included in the survey were Environmental Defense Fund, Greenpeace, National Audubon Society, National Wildlife Federation, Nature Conservancy, Natural Resources Defense Council, and Sierra Club.

quality benefit values differ across the population based on their usage status.[26] Although it is not feasible to distinguish pure nonuse, passive use, or option values, the results do highlight how benefit values vary with recent usage of lakes and rivers.[27] As expected, respondents who have visited a lake or river in the last 12 months have higher benefit values. We distinguish two different types of water quality usage. The first is the number of visits to lakes and rivers in the last 12 months, which has the expected positive effect. The second variable is the total number of these visits in the last 12 months that were outside the region. Whereas the behavioral scope test discussion focused on whether the respondent fell into different categories of usage—no visits, only local visits, and visits including those outside the region—the variables in Table 1 are in terms of the number of such visits, thus taking into account the actual number of trips. A trip outside the region more than doubles the effect on valuations compared to the effect of a trip within region. Thus, the effect on the log of the benefit value of having one within-region lake or river visit in the past year is 0.0316, but if that one visit is outside the region, the effect on the log of benefits is 0.1044 (i.e., $0.0316+0.0728$). Thus, a person who makes one visit per year to a lake or river that is outside the region has a 10% higher value of water quality. Although the water quality improvements in the survey are within region, this result is consistent with those who make river and lake visits outside the region having a higher intensity of preference for water quality.

The final four variables in Table 1 allow us to test for aspects of the survey structure and the characteristics of the choices that may affect the estimated values.[28] The base water quality level is defined as the lower water quality value in the choice pair in the first choice question. Thus, it would be 40% Good water quality in Fig. 1. As this base level increases, the unit benefit value declines, reflecting diminishing marginal value of water quality levels across respondents, consistent with standard economic assumptions. In and of itself, being told the national water quality percentage is 65% Good does not affect average benefit values so that it is not influential as a separate reference point. But when the national water quality average is interacted with the base water quality, it alters the pattern of valuation. Receiving the national water quality information roughly doubles the extent to which the log of the benefit values decline as water quality is improved from the base amount ($-0.4392-0.4455=-0.8847$), while those without that information display no diminishing valuation ($-0.4392+0.4455=0.0063$). This drop-off suggests that respondents use the national information as a reference point to place the base water quality information in context. When the national reference point is known, substantial improvements beyond the base level are less highly valued, but when the base is below the national value then improvements are more highly valued. Put differently, people are willing to pay more for regional improvements when they are below the national average.[29]

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[26] Other estimates of water quality benefits in the literature are not comparable because of the difference in the water quality scale. For discussion of the differences, see Magat et al. (2000). For examples of earlier benefit estimates, see Smith and Desvousges (1986) and Carson and Mitchell (1993).

[27] Distinguishing nonuse and passive use values has long posed considerable problems for such studies. See Smith (1987), Bishop and Heberlein (1990), Bishop and Welsh (1992), Freeman (2003), and Eom and Larson (2006).

[28] These four variables have been zero-centered, which is to say that each observation is adjusted by subtracting from it the mean of all observations of the variable.

[29] In an additional analysis, respondents who accurately gauged the water quality in their region (based upon state quality) relative to the national average did not have significantly different values for improvements than those who did not (any respondent whose estimate was within 10% points was deemed accurate, so a respondent in a 55% Good state would be accurate stating either average or below average). However, those who believed their region to have higher than average water quality did have a higher value for water quality improvements in their move to the new hypothetical region.

Table 4 Logit regression of probability of choosing higher cost, higher quality region[a]

Variable	Parameter estimate	Asymptotic standard error
Log (starting water quality tradeoff)	−0.8672*	0.0941
Intercept	2.3207*	0.2624

[a] *Notes*: *significant at the .01 level, two-tailed test. $N = 3{,}757$ with 1,810 choosing region 1 and 1,947 choosing region 2 on their initial choice

The final variable in Table 1 is the log of the initial tradeoff ratio embodied in the first choice offered in the survey. Thus, this is the value of the water quality given by Eq. 2 if the respondent is indifferent. The positive sign indicates a respondent revealed a higher tradeoff rate if the initial tradeoff rate is high. Ideally, a survey should be neutral with respect to such possible anchoring effects caused by the initial starting tradeoff rate in the initial regional choice pair.[30] To achieve neutrality, in Huber et al. (2007) we have developed a proposed approach that controls for potential bias. What we term the "equitable tradeoff" rate is the initial tradeoff rate v_0 that yields a 50–50 split on the initial choice in the iterative choice decision tree. This split is desirable for two main reasons. First, if an analyst has no information about a person's value, then the greatest gain in knowledge (decrease in entropy) comes from giving a choice that separates the respondent from half the people in the survey. Second, this method does not lead respondents to express valuations in a particular direction. To the extent that the initial question might affect responses, it is best to use a technique for choosing the initial question that depends upon respondent decisions, not analysis or policymaker preferences.

To estimate this equitable tradeoff rate we use the results in Table 4, which reports the logit regression results for the probability of choosing the high cost-high water quality region on the initial choice as a function of the log of the initial tradeoff rate v_0. This starting tradeoff rate variable has the expected negative effect. Based on this equation, the initial benefits tradeoff rate that will produce an average 50–50 split across the sample is $14.52. Using this value as the starting tradeoff rate in the regression estimates in Table 1 along with the actual values of the other explanatory variables provides an estimate of the water quality benefits at the equitable tradeoff starting point. The result is a mean water quality benefit value of $31.70 with a median of $13.23, which is quite similar to the unadjusted mean value of $33.43 and median of $13.77.

It is important to note that in this case the adjustment for an equitable starting ratio makes almost no difference in our results. That, however, is due to an attempt on our part to structure the survey options using initial ratios so that the split down the iterative tree is equal in both directions. Our sample had 48% of non-indifferent respondents initially choosing the high cost, high quality region. Thus, while the parametric adjustment for lack of equitable starting ratio made little difference in this case, had our empirical distribution deviated substantially from the 50–50 split then the valuations could have been quite different. For instance, if our respondents had exhibited a 40–60 split, with 40% of respondents choosing the high cost option, then we estimate that the unadjusted water quality estimate would jump to $40.48.

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[30] DeShazo (2002) discusses anchoring effects in such contexts.

Table 5 Validity tests based on two-limit censored regression of log of unit water quality benefit values[a]

Variable	Demographic variables included		Demographic variables not included	
	Parameter estimate	Standard error	Parameter estimate	Standard error
Subject stopped and continued survey later	−0.0802	0.0749	−0.0919	0.0772
Time as panel member, in months	−0.0017	0.0012	−0.0001	0.0012
Days from invitation to completion	−0.0039	0.0025	−0.0067*	0.0025
Respondent retired from KN panel	−0.0053	0.0592	−0.0887	0.0607
Intercept	0.5547**	0.2605	2.6951*	0.0382
Pseudo R-Squared	0.0209		0.0010	

[a] *Notes*: *significant at .01 level, **significant at .05 level, both two-tailed tests. Results are for the consistent sample of 4,033, including 376 left censored and 403 right censored observations. The demographic variable set includes all variables in Table 1

3.2 Effects of the Survey Administration Mode on Results

It is important that the distinctive attributes of respondents in a decentralized, self-paced administration of a computer-based survey not affect the water quality valuations. In particular, survey attributes particular to this survey administration mode are the time the respondent has been in the panel, the days from invitation to completion, whether the respondent stopped and continued the survey later, and whether the respondent retired from the panel within 5 months of their survey round. The effects of these variables are shown in Table 5. The first model includes the same demographic variables as Table 1, while the second model uses only the four variables described above.

Respondents who are less engaged in the survey task or are not focused on completing the survey may have a worse grasp on the concepts conveyed in the survey, and therefore have different water quality values. To capture this influence, we collected data on whether the subject stopped and continued the survey at a later time. Overall, 7.76% of the respondents interrupted their survey at some point. This variable has no significant effect on benefit values, though the coefficient was negative. A negative effect would make sense if a break reflected less interest in the survey topic, and therefore less interest in water quality improvements. The fact that those who take such a break are slightly less likely to have visited a lake or river in the last 12 months is consistent with this interpretation.

Long-term panel members may be more proficient at taking computer-based surveys, and this experience conceivably may affect their valuations, though the direction of the effect is unclear. To reflect such factors, we used data for the amount of time, in months, that each respondent has been in the KN panel. This variable has a mean of 24 months. Because KN rotates their panels periodically, there is reduced risk of respondents suffering from survey fatigue or becoming survey respondent professionals. The time in panel variable does not have a significant effect on water quality values when other explanatory variables are excluded, but it is statistically significant in the first equation that includes the full set of explanatory variables. The magnitude of the effect is quite small, implying a less than 3% lower water quality value for a full additional year in the panel.

Respondents who quickly accept the invitation to participate in the survey may reflect a greater interest in the survey topic and therefore be a self selected sample with a higher water quality value compared to respondents who wait or need to be reminded to participate. Those who took longer might also reflect a lack of interest in taking surveys generally, or may simply reflect a busy schedule. The number of days that the respondent took to complete the survey after first being given the opportunity to participate was noted, and has a mean of 4.96 days. Taking into account the full set of demographic variables eliminates the statistical significance of this variable that is exhibited in the second equation in Table 5. The days from invitation to completion may serve as a proxy for the influence of the demographic determinants of water quality values. The magnitude of the effect in the second equation is a 0.67% lower water quality benefit value per day of delay from invitation to survey completion.

Some panel members may experience diminishing interest in taking surveys, or perhaps a decrease in interest in surveys due to taking ours. The final survey panel variable is for whether the respondent retired from the panel within 5 months after taking the survey. This variable does not have a statistically significant effect on water quality valuations.

Overall, these results give confidence that the stated preference results are robust to sampling and survey implementation issues. The series of tests on these key attributes of the panel form of survey administration do not reveal any substantial biases in the benefit estimates. These results are encouraging, as web-based panels offer a variety of advantages over other survey modes, including lack of interviewer bias, greater willingness to provide confidential information, and uniform presentation of the survey to all respondents.

4 Conjoint Benefit Estimates

The survey also included two sections of conjoint tasks, one estimating tradeoffs between costs and water quality and the second estimating tradeoffs between improvements in lakes versus rivers. The first set of results serves as a corroboration of the iterative choice methodology, while the lakes versus rivers conjoint analysis will be important for the policy analysis in Sect. 5.

The water quality conjoint task included these dimensions: annual costs of the policy, water quality improvement in the region, and year when the improvement begins. The matter of interest here is the implied water quality-cost tradeoff resulting from the series of five conjoint choices that each respondent made based on conjoint decisions such as that in Fig. 1.

We use a standard random utility framework to derive the water quality values.[31] More specifically, we estimate a conditional logit model that uses a linear utility function u_{mi} for choice m of person i that takes the form

$$u_{mi} = \alpha w_{mi} + \beta c_{mi} + \gamma t_{mi} + \varepsilon_{mi}. \tag{6}$$

The matter of interest is the cost-water quality tradeoff. Taking total derivatives of this equation and setting $\mathrm{d}t = 0$, yields

$$\frac{\partial c}{\partial w} = \frac{-\alpha}{\beta}. \tag{7}$$

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[31] See Train (2003) for a general discussion of random utility models.

Table 6 Conditional logit estimates of policy choice from the conjoint exercise[a]

Variable	Coefficient (asymptotic std. error)		
	Conditional logit, all questions	Conditional logit, question 1	Mixed logit, all questions
Water quality improvement	0.1205*(0.0022)	0.1348*(0.0055)	0.3265(0.2143)
Cost	−0.0052*(0.0001)	−0.0054*(0.0003)	−0.0123(0.0010)
Delay	−0.2634*(0.0052)	−0.3013*(0.0135)	−0.6869(0.4908)

[a] *Notes*: *significant at the .01 level, two-tailed test. Results are for the consistent sample for which the conjoint questions were asked, 2,914 respondents, asked five questions, each of which with three choices. Numbers in parentheses are standard errors for the conditional logit results and standard deviations for the mixed logit estimates

Table 6 reports conditional logit estimates of the model using both the full sample of five conjoint choices as well as the initial choice only. In each instance, water quality improvements have the expected significant positive effect on choosing the policy, while cost has the expected significant negative effect. The valuations are also positively correlated with the stated preference results.[32] The implied tradeoff rate based on the conditional logit estimates in Table 6 is $23.17 based on all choices and $24.96 based on the first question. These values are somewhat below the average stated preference value of $33.43. These differences are modest given that the conjoint survey varies in three fundamental ways: the iterative nature of the stated preference choices, the overall structure of the survey task, and the payment mechanism—annual costs of a policy versus cost of living associated with a regional location choice. Moreover, the econometric structure of the random utility model produces estimates that are more reflective of the median of the valuation distribution rather than the mean of the skewed distribution of water quality values.

A further test of the robustness of the results is based on a mixed logit analysis of the conjoint results using a hierarchical Bayes estimation technique. These results appear in the final column of Table 6. The implied tradeoff between water quality and money based on the mixed logit estimates is $26.50. The pattern of coefficient effects is quite similar to the conditional logit estimates, and the magnitude of the tradeoff rate is in line with the conditional logit estimates. Unlike the conditional logit estimates, mixed logit values account for respondent heterogeneity and do not require an assumption of independence of irrelevant alternatives. For simplicity, the models in Table 6 suppress the role of policy-personal characteristic interactions and estimate average values across the sample. Personal characteristics other than interactions drop out of the analysis.

The final conjoint component considered a series of iterative choices involving improvement in lakes versus rivers so as to establish the rate of tradeoff between these two types of water bodies.[33] The conjoint model elicited values for water quality on three different dimensions: fishing, swimming, and the aquatic environment. Using a random utility model similar to that for water quality versus cost implies that a 1.13% improvement in lakes is

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[32] Because the stated preference results yield individual estimates, but the conjoint approach does not, to test for the relationship of the responses we included an interaction of the water quality improvement variable with the respondent's stated preference value. The effect was positive, as expected, with coefficient (std. error) of 1.16e-3 (7.31e-5) when added to the basic conjoint regression.

[33] Further details can be found in Huber et al. (2006).

equivalent to a 1% improvement in rivers, or relative weights of 0.531 for lakes and 0.469 for rivers. There are only minor differences in these water quality values.

5 Policy Application

The magnitude of the water quality values implied by these results on policy can be illustrated using the data on the trends in water quality reported in the EPA's National Water Quality Inventory. More specifically, the results can be used to estimate the economic value of the decline in water quality from 1994 to 2000.[34]

First, we must construct a measure of the average water quality in these 2 years. The percentage of lake acres rated "Good" dropped from 63% to 54% over that period, while the percentage of river miles rated "Good" fell from 64% to 61%. Using the relative conjoint valuation weight of 0.531 for lakes and 0.469 for rivers, the average water quality overall is

$$\text{National Water Quality in 1994} = 0.531(63\%) + 0.469(64\%) = 63.5\%. \tag{8}$$

Similarly, for the year 2000 the water quality rating is given by

$$\text{National Water Quality in 2000} = 0.531(54\%) + 0.469(61\%) = 57.3\%. \tag{9}$$

Overall, there was a decline in weighted average water quality of 6.2%.

Using the equitable tradeoff average value of \$31.70 for how much people value water quality in their region, there is a loss of 6.2%, or \$196.54 per household per year. This estimate is a lower bound because it includes only the within region value, effectively assuming zero value for water quality changes outside one's region. There is an additional conservative aspect to this estimate, since this calculation provides an estimate of a loss of the percentage of water rated "Good." Our iterative stated preference estimates value neutral levels of water quality value, but in practice people tend to value losses more highly than gains. Numerous studies have documented various loss aversion phenomena, and to the extent that the greater valuation per unit of losses stems from a rational preference that regards these losses as more consequential to utility than comparable amounts of gains, our estimates of the loss in water quality benefits will understate the actual loss amounts. Based on the national number of households of 111 million,[35] the loss per household implies a total annual loss of \$21.8 billion. Even this lower bound estimate indicates the substantial economic value of the decline in water quality as well as the direct policy applicability of the results.

6 Conclusion

The iterative choice stated preference survey structure for eliciting values affords considerable insight into how people value water quality based on the US EPA National Water Quality Inventory ratings. Because the survey focused on the value of water quality rated "Good" on several dimensions, which is also a policy focus of the EU water quality definitions, the methodology also may be useful in constructing benefit values within the context of the EU Water Framework Directive. The procedure incorporates individual respondent dominance tests as part of the structure that makes it possible to identify non-rational respondents. Due to the skewed nature of the water quality benefit value distribution, the mean unit benefit value

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[34] Unfortunately, water quality data after 2000 have not yet been released.

[35] US Department of Commerce (2003).

of $32 exceeds the median value. The choice-based conjoint estimates of a $25 unit benefit value based on the conditional logit estimates and $27 based on the mixed logit estimates are of the same general magnitude as the iterative choice value, but smaller. The choice-based conjoint estimates do not capture the heterogeneity of skewed water quality value distribution to the same extent as do the iterative choice results that yield valuations for every respondent. The economic determinants of water quality benefit values, such as income and visits to water bodies, followed the expected general patterns of influence. These stated preferences passed a variety of scope tests, including refined tests with respect to behavioral scope, affective scope, and cognitive scope. Diminishing marginal valuations of water quality improvements as the base water quality level rises also accord with economic theory.

The findings here also have more general ramifications for survey implementation in other contexts. To limit the anchoring influence of the initial choice we propose the use of equitable starting tradeoffs in which there is a 50–50 split in the initial binary regional choice. Because of the balanced nature of our choice sets, this adjustment alters the mean water quality value by only $1, or about 3%, but it nevertheless provides a survey validity reference point for future studies that seek to minimize the role of anchoring effects.

The survey results did not resolve some long-standing issues regarding environmental benefits. We did not, for example, disentangle the influence of passive use, option values, and related concepts. What the results did show is that even those who do not use lakes or rivers have substantial values, but these values are much greater for those who use such water bodies, particularly if they make such trips outside the region. How much people value water quality also depends on whether the regional water meets national average standards, as marginal water quality benefits are substantially higher for those who are under the revealed national level. The influence of national reference points embodies effects that could be rational concerns or simply reflect a type of anchoring effect. As with the use/nonuse distinction, disentangling the underlying components of these valuations remains a difficult task.

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