



Improving environmental valuation estimates through consistent use of revealed and stated preference information

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Received 18 September 2003

Abstract

Environmental valuation data from stated and revealed preference methods are integrated into a unified model of preferences for environmental quality improvement that identifies the “use” and “nonuse” components of the total value estimate. This articulates clearly what parts of the total value estimate come from each type of data, and permits tests of whether estimated preferences satisfy weak complementarity between the environmental good of interest and related private goods. The statistical advantages of using more information for the valuation problem are exploited, while retaining flexibility to identify value estimates from any individual method of analysis.

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JEL classification: Q25; Q26

Keywords: Environmental valuation; Nonuse value; Weak complementarity; Stated preference; Revealed preference

1. Introduction

There is a wide recognition that environmental amenities or quality improvements may provide benefits in the form of nonmarketed or public goods, and that nonuse or “passive use” value can be an important component of total nonmarket benefits in addition to use value [30,42,19,3]. Different nonmarket valuation methods have varying capabilities of measuring these nonmarket benefits. For instance, the revealed preference approach measures “use value,” the part of the total benefits reflected by changes in (compensated) demands for related private goods. In contrast, the stated preference approach in principle measures the total benefits directly, so captures both use and nonuse value. In addition, it is generally well-appreciated that each individual approach has its own strengths and weaknesses [12,37,41,4]. Because of this, economists working on nonmarket valuation problems have turned increasingly to the use of multiple methods for assessing environmental values, as has been done elsewhere in the literature [14,8,15,27].

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One of the most common ways of using multiple methods is to combine actual behavior with statements of value, e.g., by collecting information on recreation trips to a resource whose quality changes and asking respondents their willingness to pay (WTP) for those same quality changes. Trips information is used to estimate a recreation demand function, while WTP responses are used to estimate a WTP function for quality improvements. The demand function provides estimates of use value, while the WTP function gives estimates of the total value (TV) of the quality change, which may consist of a nonuse value component in addition to use value.

There are some important reasons why researchers need to pay attention to the use-related and nonuse-related parts of the TV of environmental amenities when using multiple methods for a single valuation problem. One is simply that policymakers may be interested in what part of the value of a resource is related to direct use, and what is nonuse value related. A more fundamental reason, though, is that in combining data from multiple sources rigorously (i.e., with a coherent underlying model of consumer preferences), one cannot escape having to know what parts of the combined model are being generated from which data. In the example of combining demand and WTP data, since one measures use value and the other measures TV, the two models will have some, but not necessarily all, preference parameters in common.¹ Knowledge of which parameters enter different parts of the model is necessary for theoretically consistent joint estimation, and is tantamount to knowing the expressions for nonuse (as well as use and total) value. There may also be a statistical advantage of combining data, either from reducing biases to or variance of the estimate of WTP for the quality change [28].

Consistency of the modeling approach to a nonmarket valuation problem can be evaluated both in terms of the functional forms used for the demand and WTP functions, and in the internal consistency of the value estimates generated. An adequate empirical model must be able to rationalize both sets of data as consistent with a single underlying model of preferences for use and environmental quality. This means that (a) the functional forms of demand and WTP should be consistent with a utility or expenditure function; (b) the parameters appearing in both the demand and WTP functions should be the same, and satisfy the requirements of choice theory; and (c) the use and nonuse value estimates generated from the model should be internally consistent. In particular, nonuse value should be traceable to parameters that appear only in the WTP function.

While several interesting recent papers have addressed one or more aspects of this problem,² none has succeeded completely in developing and estimating an integrated model of demand and WTP to produce internally consistent estimates of use and nonuse value of environmental quality changes. Cameron [6] estimated a model of demand and WTP based on a quadratic direct utility function, but this model did not produce separate estimates of use and nonuse value. Niklitschek and Leon [40] combined WTP statements with statements of intended use, but the preference function they use explicitly excluded the presence of nonuse value. Huang et al. [25] estimate a demand function and a variation function (which generates Marshallian estimates of WTP), but the functional forms of the two were not internally consistent with a model of preferences.

This paper develops and demonstrates a convenient-to-use, theoretically consistent empirical framework for estimating use, nonuse, and TVs of quality changes by combining revealed (TCM) and stated preference (CVM) data for improvement of environmental quality. Beginning from a commonly used Marshallian recreation demand function (the semilog function, which relates log quantities to the levels of covariates) and integrating back to recover the implied quasi-expenditure function, the part of quasi-preferences that may generate nonuse value is identified. By parameterizing this part of preferences (which is the constant of integrating back from demand), and using the resulting empirical form of the quasi-expenditure function to derive compensating variation expressions, functional forms for WTP that are consistent with the demand function are obtained.³

¹Generally all the demand parameters will also appear in WTP, but WTP may also depend on parameters not shared with demand.

²These include Adamowicz et al. [1], Cameron [6], Dickie et al. [13], Earnhart [16], Eom and Smith [18], Haener et al. [20], Huang et al. [25], and Niklitschek and Leon [40].

³One could also do this by specifying an expenditure or utility function for preferences and deriving the associated demand(s). In practice, this may not be as transparent a way of identifying the class of functions that can represent nonuse value in a given preference function; this is identified directly by the constant of integration in the integrating back approach.

The WTP function has parameters associated with both use and nonuse value, while the demand function only contains parameters pertaining to use value. When demand and WTP are jointly estimated using both TCM and CVM data, the stated preference (CVM) responses provide the information needed to estimate the nonuse parameters, while both the stated and revealed (CVM and TCM) responses provide information for estimating use value parameters. The result is a complete characterization of the individual valuation of the quality change, including the TV and the part of this value that will be found in the demand behavior (use value) and the part that is not (nonuse value). It permits several innovations in the empirical estimation of nonuse value, including (a) testing for its presence as restrictions on the parameters of the preference function and (b) allowing it to vary systematically with individual characteristics, much the way demand does.

This strategy is attractive as it allows the data collected on multiple “windows” to an individual’s values to be used consistently within an underlying preference structure. Joint estimation provides more structure for parameter estimation and uses both sources of information more efficiently. It permits an assessment of the use, nonuse, and TV of a quality change without resorting to behavioral restrictions such as often-invoked weak complementarity, which implies zero nonuse value. Instead, whether preferences exhibit weak complementarity is a testable proposition within the model, as a restriction on the nonuse value parameters.⁴

Section 2 develops the theoretical framework for identifying use and nonuse value and testing for weak complementarity, while Section 3 lays out the estimation model. The data used in the empirical application are described in Sections 4, and Section 5 presents and discusses the empirical findings. Section 6 concludes.

2. Theoretical framework

The starting point for utility-theoretic analysis is the individual’s utility maximization problem, which can be written as

$$\text{Max}_{x,z} u(x, z, q) \quad \text{s.t. } m = px + z, \quad (1)$$

where for simplicity x is recreational visit frequency with corresponding price p , and z is a numeraire good with unit price. Other goods are suppressed in the notation as a matter of convenience, without loss of generality. The variable q represents a water quality variable and is assumed to be a public good not chosen by the individual, while m is household income. The utility function $u(\cdot)$ is the individual’s continuous, differentiable and quasi-concave utility function. Water quality, q , is assumed to be a good, so that it enters the preference structure such that $\partial u / \partial q > 0$.

Solving the constrained utility maximization problem yields the Marshallian demand for trip frequency $x = x(p, q, m)$, which is specified empirically with the semilog functional form⁵

$$x(p, q, m) = \exp(\alpha + \beta p + \gamma q + \delta m), \quad (2)$$

where α , β , γ , and δ are demand parameters. Substituting this trip demand into the utility function yields the indirect utility function $V(p, q, m) = u(x(p, q, m), z(p, q, m), q)$, whose inverse with respect to income argument is the minimum expenditure function

$$E(p, q, u) \equiv \min_{x,z} \{px + z : u(x, z, q) = u\},$$

which is used for measuring welfare changes. Given the assumption that q is a good, $E(p, q, u)$ is decreasing in q (i.e., $\partial E / \partial q < 0$).

When one integrates back to obtain the preferences underlying a given demand function, what is recovered is the quasi-expenditure function [23], which does not contain all the information about preferences, but which does contain all the relevant information for welfare analysis when own-price p changes [32]. The reason is that integrating back results in a constant of integration that may depend on other prices and on quality,

⁴This contrasts with the analysis of Herriges et al. [24], who point out that when one combines information from two revealed preference methods, weak complementarity cannot be tested for. This is discussed in more detail below.

⁵Among commonly used simple functional forms for single-equation demands (such as linear, quadratic, and Cobb–Douglas), researchers have often concluded that semilog functions perform better in terms of goodness of fit and the magnitude of estimated welfare measures [45,36,43]. Integrating back to recover quasi-preferences is also straightforward [31].

though not on own price. Depending on how quality enters the constant of integration, preferences may or may not exhibit weak complementarity of q to x (i.e., absence of nonuse value). Demand behavior alone cannot determine this, though stated preference information can.

To obtain the quasi-expenditure function implied by (2), one can note the identity (through Shephard's Lemma) of the price slope of the expenditure function to Hicksian demand, and the identity relating Hicksian demand to Marshallian demand when money income is replaced by the expenditure function:

$$\partial E(p, q, u) / \partial p = x^h(p, q, u) = x(p, q, E(p, q, u)), \quad (3)$$

where $E(p, q, u)$ is the expenditure function and $x^h(p, q, u)$ is the Hicksian or compensated demand function.

Given the semilog specification of trip demand x , Eq. (3) solves for the quasi-expenditure function

$$\tilde{E}(p, q, \theta(q, u)) = -\frac{1}{\delta} \ln \left(-\frac{\delta}{\beta} e^{(\alpha + \beta p + \gamma q)} - \delta \theta(q, u) \right), \quad (4)$$

where $\theta(q, u)$ is the constant of integration that, in general, depends on quality q [21,23]. If one were concerned only about the welfare consequences of own-price changes, as in Hausman [23], $\theta(q, u)$ could be set to the utility index u . As it happens, that particular parameterization of $\theta(q, u)$ implies weak complementarity of x and q for the semilog demand function.⁶ In general, however, one would expect $\theta(q, u)$ to be a function of q , and, consequently, for there to be nonuse value. Thus, $\theta(q, u)$ is the source of nonuse value in the semilog demand model.

In anticipation that CVM responses can be used to identify the parameters of nonuse value, it is logical to specify $\theta(q, u)$ as a function of q and u . For this analysis, it is assumed that $\theta(q, u) = e^{\delta \psi q} u$.⁷ Substituting this into (4), the empirical form of quasi-expenditure consistent with the semilog demand in (2) is

$$\tilde{E}(p, q, u) = -\frac{1}{\delta} \ln \left(-\frac{\delta}{\beta} e^{\alpha + \beta p + \gamma q} - \delta e^{\delta \psi q} u \right). \quad (5)$$

This quasi-expenditure function is defined for $0 \leq x < -\beta/\delta$; i.e., $e_{pp} < 0$ and $x \geq 0$ over this range. The quasi-indirect utility function corresponding to (5) is

$$\tilde{V}(p, q, m) = \left(-\frac{1}{\delta} e^{-\delta m} - \frac{1}{\beta} e^{\alpha + \beta p + \gamma q} \right) e^{-\delta \psi q}. \quad (6)$$

It is notable that no preference restrictions (such as weak complementarity) are imposed on this expenditure function (other than the functional form for $\theta(q, u)$), so that depending on the value of ψ , there may be nonuse value in addition to use value. As seen formally below, if the hypothesis that $\psi = 0$ is rejected, nonuse value is present in the estimated preferences.

2.1. Measures of total, use, and nonuse value

Now suppose water quality is improved from q^0 to q^1 due to the implementation of a government policy. Measures of use, nonuse, and TV of this quality improvement can be obtained from the quasi-expenditure function. Individuals' WTP for, or TV of, this quality change can be represented by a compensating variation measure, defined as the maximum amount of income that individuals would give up in order to enjoy the quality improvement, holding utility constant. It can be expressed as the change in the expenditure function as quality changes from q^0 to q^1 given utility is held constant at the reference level u_0 , which is determined from Eq. (6) evaluated at the initial quality level,

$$u_0 = \left(-\frac{1}{\delta} e^{-\delta m} - \frac{1}{\beta} e^{\alpha + \beta p + \gamma q^0} \right) e^{-\delta \psi q^0}. \quad (7)$$

⁶This point is demonstrated formally below.

⁷For incomplete demand systems there are many quasi-expenditure functions, differing only in the form of $\theta(q, u)$ (i.e., in the nonuse value specification), that generate the same demands [32]. Given a functional form for nonuse value, the data determine parameter values that best explain observed choices and stated preferences. Our empirical analysis treats ψ as a function of individual characteristics to provide considerable flexibility in the nonuse value specification.

Using (7) in (6), the TV of the quality change is⁸

$$\begin{aligned}
 TV(q^0, q^1) &= \tilde{E}(p^0, q^0, u_0) - \tilde{E}(p^0, q^1, u_0) \\
 &= \frac{1}{\delta} \ln \left[-\frac{\delta}{\beta} e^{(\alpha+\beta p+\gamma q^1+\delta m)} + \left(1 + \frac{\delta}{\beta} e^{\alpha+\beta p+\gamma q^0+\delta m} \right) e^{\delta\psi(q^1-q^0)} \right].
 \end{aligned}
 \tag{8}$$

Eq. (8) is the expression for WTP by the recreationist responding to a valuation question. Upon noting that $e^{(\alpha+\beta p+\gamma q^1+\delta m)} = x^1$ is the Marshallian quantity demanded after the quality change and $e^{\alpha+\beta p+\gamma q^0+\delta m} = x^0$ is Marshallian quantity demanded before the quality change, TV can be written succinctly as

$$TV(q^0, q^1) = \frac{1}{\delta} \ln \left[-\frac{\delta}{\beta} x^1 + \left(1 + \frac{\delta}{\beta} x^0 \right) e^{\delta\psi(q^1-q^0)} \right].
 \tag{9}$$

A comparison of the TV expression in Eq. (9) with the demand function in Eq. (2) confirms that ψ is central to “nonuse” value as it does not appear in the demand function. In fact, (9) makes quite clear the parts of TV that do depend on demand (x^0 , x^1 , and the parameters β and δ), as well as that (the arguments of ψ) which does not.

To develop a joint estimating model which combines CVM information on TV with TCM data on use value, it is necessary to articulate more precisely the way in which (9) encompasses use and nonuse values, respectively. The standard decomposition of TV into use and nonuse components follows the logic of Mäler [34] and McConnell [35], which involves adding and subtracting the terms $\tilde{E}(\hat{p}^0, q^0, u_0)$ and $\tilde{E}(\hat{p}^1, q^1, u_0)$ from (7), with \hat{p}^0 and \hat{p}^1 being the Hicksian choke prices given the initial and subsequent quality levels. Terms then can be grouped as

$$\begin{aligned}
 TV(q^0, q^1) &= \{[\tilde{E}(\hat{p}^1, q^1, u_0) - \tilde{E}(p^0, q^1, u_0)] - [\tilde{E}(\hat{p}^0, q^0, u_0) - \tilde{E}(p^0, q^0, u_0)]\} \\
 &\quad + \{\tilde{E}(\hat{p}^0, q^0, u_0) - \tilde{E}(\hat{p}^1, q^1, u_0)\}
 \end{aligned}
 \tag{10}$$

$$\begin{aligned}
 &= \left\{ \int_{p^0}^{\hat{p}^1} x^h(p, q^1, u_0) dp - \int_{p^0}^{\hat{p}^0} x^h(p, q^0, u_0) dp \right\} + \int_{q^1}^{q^0} \frac{\partial \tilde{E}(\hat{p}, q, u_0)}{\partial q} dq \\
 &= UV(q^0, q^1) + NUV(q^0, q^1).
 \end{aligned}
 \tag{11}$$

The first term in Eq. (11), $UV(q^0, q^1)$, is “use value,” the difference in areas under the Hicksian demand as it shifts with the quality change; it is the Hicksian counterpart to the change in consumer’s surplus one would calculate with a demand shift. The second term in (11), “nonuse value,” is the difference in minimum expenditure for the quality change given that x is not being consumed; this is the part of TV unrelated to use of x .

To determine the mathematical expressions for use and nonuse value corresponding to the empirical semilog demand function in (2), the expressions for $\tilde{E}(\hat{p}^0, q^0, u_0)$ and $\tilde{E}(\hat{p}^1, q^1, u_0)$, are needed. To obtain these, note that the Hicksian demand, obtained by differentiating (5) with respect to p , is

$$x^h(p, q, \theta(q, u)) = e^{(\alpha+\beta p+\gamma q)} \left/ \left[-\frac{\delta}{\beta} e^{(\alpha+\beta p+\gamma q)} - \delta g(q)u \right] \right. .
 \tag{12}$$

The denominator of (12) is strictly positive since Hicksian quantities are positive and finite. This means that the Hicksian choke price $\hat{p}(q, u) \equiv \min\{p : x^h(p, q, u) = 0\}$ is infinity (provided the own-price coefficient β is negative) for all q . Substituting this into the quasi-expenditure function, when x is not being consumed the quasi-expenditure function is

$$\tilde{E}(\hat{p}(q, u), q, \theta(q, u)) = -\frac{1}{\delta} \ln[-\delta e^{\delta\psi q} u].
 \tag{13}$$

⁸The full derivation of Eq. (8) is omitted for brevity since the results for this functional form for preferences are well known [21,23,31].

Thus, nonuse value for this quasi-expenditure function is

$$\begin{aligned} NUV(q^0, q^1) &= \tilde{E}(\hat{p}^0, q^0, u_0) - \tilde{E}(\hat{p}^1, q^1, u_0) \\ &= -\frac{1}{\delta} \ln[-\delta e^{\delta\psi q^0} u_0] + \frac{1}{\delta} \ln[-\delta e^{\delta\psi q^1} u_0] \\ &= \psi[q^1 - q^0] \end{aligned} \quad (14)$$

since the term $\frac{1}{\delta} \ln[-\delta u_0]$ cancels from both expenditure function terms.

Use value can then be determined either by the first four expenditure function terms in Eq. (10)⁹ or by subtracting nonuse value (Eq. (14)) from TV (Eq. (8)):

$$\begin{aligned} UV(q^0, q^1) &= TV(q^0, q^1) - NUV(q^0, q^1) \\ &= \frac{1}{\delta} \ln \left[-\frac{\delta}{\beta} x^1 + \left(1 + \frac{\delta}{\beta} x^0 \right) e^{\delta\psi(q^1 - q^0)} \right] - \psi[q^1 - q^0]. \end{aligned}$$

Dividing the argument of the natural logarithm by $e^{\delta\psi(q^1 - q^0)}$ and extracting this term from the natural logarithm, the expression for use value simplifies to

$$UV(q^0, q^1) = \frac{1}{\delta} \ln \left[-\frac{\delta}{\beta} x^1 e^{-\delta\psi(q^1 - q^0)} + \left(1 + \frac{\delta}{\beta} x^0 \right) \right]. \quad (15)$$

Use value in Eq. (15) contains the nonuse value term ψ ; this is the reason why some behavioral assumption, like weak complementarity, is necessary to measure use value. As Bockstael and McConnell [5] pointed out, when quality changes, the amount by which Marshallian demand shifts is known from the demand function, but the amount by which the Hicksian demand (the basis for measuring use value) shifts cannot be determined from demand alone. Herriges et al. [24] echo the often-overlooked point that one cannot even measure use value from revealed preference information alone without some unverifiable assumption about preferences, and that the magnitude of use value (as well as nonuse value) depends on that assumption. Eq. (15) makes clear that use value will vary depending on what is assumed about ψ .

A number of previous papers have made a behavioral assumption about preferences, which is tantamount to choosing the value for ψ [33]. The empirical approach of this paper is to combine data from both CVM and TCM to estimate ψ along with the demand parameters. This avoids the need to impose a priori restrictions on how quality affects preferences (aside from the usual maintained hypothesis about functional form).

2.2. Testing for weak complementarity

Before turning to the empirical model, it is useful to verify the use and nonuse value that arise under weak complementarity. Quasi-preferences are weakly complementary if they satisfy $\partial \tilde{E}(\hat{p}, q, \theta(q, u)) / \partial q = 0$ [34,35]; that is, the quasi-expenditure function does not change as quality changes when the weakly complementary good (x in this case) is not consumed—that is, when its price is the Hicksian choke price \hat{p} . The quasi-expenditure function when x is not consumed is given in Eq. (13), and its derivative with respect to quality is

$$\partial \tilde{E}(\hat{p}, q, \theta(q, u)) / \partial q = -\psi \quad (16)$$

which is zero when $\psi = 0$.¹⁰ Under this condition, preferences exhibit weak complementarity, and use and nonuse value are, from (15) and (14), respectively,

$$\begin{aligned} UV(q^0, q^1) &= \frac{1}{\delta} \ln \left[1 - \frac{\delta}{\beta} (x^1 - x^0) \right], \\ NUV(q^0, q^1) &= 0. \end{aligned}$$

⁹It is straightforward to verify this using the quasi-expenditure functions in Eqs. (5) and (13) evaluated at the appropriate arguments.

¹⁰More generally, weak complementarity holds for these preferences when $\partial \theta(q, u) / \partial q = 0$, since $\tilde{E}(\hat{p}, q, \theta(q, u)) = -\frac{1}{\delta} \ln[-\delta \theta(q, u)]$ and the weak complementarity condition is $\partial \tilde{E}(\hat{p}, q, \theta(q, u)) / \partial q = 0$.

The hypothesis test $H_0 : \psi = 0$ is, therefore, a test for whether preferences satisfy weak complementarity (and nonuse value is zero) within this model. It is important to emphasize that this is a joint test of both the functional form for preferences and for the absence of nonuse value.

This result is consistent with the analysis of Herriges et al. [24], who also point out that one cannot test for weak complementarity from revealed preference data alone. The parameter ψ appears in WTP but not in demand, so demand behavior is not sufficient to identify it. However, as Ebert [17] noted, one way to identify the full value of a quality change (and estimate ψ) is to introduce information about the inverse demand for quality, and CVM can be used for this purpose. Thus, by combining revealed and stated preference data, one can test whether weak complementarity holds, and distinguish which of the (infinitely many) utility functions consistent with the revealed preference data is also consistent with the stated preference data.

3. Estimation model

The data used in the empirical application of the use–nonuse value estimation methodology (explained more fully in the next section) were collected from recreational users of the Man Kyoung River (MKR) basin in South Korea. Respondents were asked about their river use, and answered a sequence of questions about whether they were willing to pay specific amounts of money for river water quality improvement. Since they actively made two behavioral decisions, how many trips to take and their WTP for water quality improvements, one can reasonably assume that both are motivated by the same preference structure. These individuals’ total valuation of a water quality improvement may contain both use value and nonuse value.¹¹ Adopting a unified preference structure for analysis provides an opportunity to jointly estimate the actual recreation demand and contingent WTP models, and to evaluate formally whether or not nonuse value plays a major part in the WTP for water quality improvement.

Use value, in our context, is the change in net economic value associated with increases in the demand for visits to recreational sites in the MKR basin. Nonuse value is the component of TV that arises independent of use. This approach to defining nonuse value allows for the possibility that users as well as nonusers might hold values that are independent of use [19].

For estimation, Eqs. (2) and (9) are assumed to represent the systematic part of preferences. The demand parameters α , β , γ , and δ appear in both the demand and WTP functions (Eqs. (2) and (8)), while the nonuse-related parameter ψ enters only into the stated WTP function (Eq. (8)). Appending a demand error η and a WTP error ε , the system of equations to be estimated can be written as

$$\begin{aligned} \ln[x(p, q, m)] &= \alpha + \beta p + \gamma q + \delta m + \eta, & (17) \\ WTP &= \frac{1}{\delta} \ln \left[-\frac{\delta}{\beta} e^{(\alpha + \beta p + \gamma q^1 + \delta m)} + \left(1 + \frac{\delta}{\beta} e^{\alpha + \beta p + \gamma q^0 + \delta m} \right) e^{\delta \psi (q^1 - q^0)} \right] + \varepsilon \\ &= TV + \varepsilon. \end{aligned}$$

The errors η and ε would not be expected to be identical because they pertain to different decisions made over different time periods (trips over the course of a year, and a value statement at a later point in time). It is likely, though, that some unobservable factors associated with the two decisions (e.g., effects of omitted demographics or attitudinal information) are part of both errors, which suggests a likely correlation between them. Thus, η and ε are assumed to follow a bivariate normal distribution $N(0, 0, \sigma_\eta^2, \sigma_\varepsilon^2, \rho)$ with different scale parameters (σ_η^2 and σ_ε^2) and correlation ρ .¹²

¹¹Including nonusers would likely provide more information about nonuse value, but would be of limited help in evaluating the approach for combining data that is our principal interest. It would be necessary to make the (strong) assumption that they are identical to users and took no trips only for reasons of price, not because of differences in preferences.

¹²This approach links the systematic parts of the two random variables, trips and WTP, as required by theory, but not their error terms. Another strategy would be to append the error η to the demands in Eq. (9) to obtain an expression for WTP error, but this would not account for other errors that are specific only to the formulation of a WTP response. For example, the WTP statement may be affected by how tightly the current period budget binds, or the information difference between the time at which trips were decided upon and the time at which WTP is stated. Accounting for the relationship between demand and WTP errors by estimating their correlation is a compromise that helps keep the model tractable.

3.1. The empirical WTP-demand model

The CVM portion of the survey followed a double-bounded (DB) format, with an initial yes–no response to an initial bid, with a follow-up yes–no question to a second bid that was higher or lower than the first, depending on the person’s response to the first question. In this discrete CVM question with follow-up format, response combinations are yes/yes, yes/no, no/yes, and no/no for a sequence of two bids, t_1 and t_2 , presented to a respondent to bound WTP. Using an experimental design in the survey, if a respondent answered yes to the first bid amount, he/she was offered with higher bid amount in the second WTP question ($t_2 > t_1$). Likewise, a respondent saying no for the first bid was assigned with lower bid amount for the second WTP question ($t_2 < t_1$).

In light of concerns about incentive compatibility of the second WTP question in DB formats (e.g., [7,2]), we use the answers to the first WTP question only and estimate a single-bound (SB) dichotomous choice WTP model jointly with demand.¹³ Probability functions for the two WTP response patterns are $P(yes) = P(WTP > t_1)$ and $P(no) = P(WTP < t_1)$. Combining respondents’ actual numbers of trips taken and WTP responses, the likelihood function for the joint decisions is

$$\mathcal{L} = \prod_{i \in no} P(x, no) \prod_{j \in yes} P(x, yes). \tag{18}$$

The joint distribution of the first term in Eq. (18), $P(x, no)$, can be written as the product of the conditional distribution of a no CVM response given x trips taken, $P(no|x)$, and the marginal distribution of trips, $\phi(x)$. Extending this decomposition to the other outcome, the likelihood function can be rewritten as

$$\mathcal{L} = \prod_{j \in no} \phi(x)P(WTP < t_1|x) \prod_{k \in yes} \phi(x)P(WTP > t_1|x), \tag{19}$$

where $\phi(\cdot)$ is the normal density function. In the first term of Eq. (19), the conditional probability function of no given x can be written as¹⁴

$$\begin{aligned} P(WTP < t_1|x) &= P(TV + \varepsilon < t_1|x) = P\left(\frac{\varepsilon}{\sigma_\varepsilon} < \frac{t_1 - TV}{\sigma_\varepsilon} \middle| x\right) \\ &= \Phi\left(\frac{((t_1 - TV)/\sigma_\varepsilon) - \rho(\eta/\sigma_\eta)}{(1 - \rho^2)^{1/2}}\right), \end{aligned}$$

where $\Phi(\cdot)$ is a standard univariate normal cumulative distribution function.

Applying this process to other response category of Eq. (19), the log likelihood function of the joint decisions associated with actual trip demand and contingent WTP responses can be expressed as

$$\begin{aligned} \text{Log } \mathcal{L} &= -\frac{n}{2} \log(2\pi\sigma_\eta^2) - \frac{1}{2} \sum_{i=1}^n \left[\frac{\ln x - (\alpha + \beta p + \gamma q + \delta m)}{\sigma_\eta} \right]^2 \\ &+ \sum_{i=1}^n (1 - I_1) \log \left[\Phi\left(\frac{((t_1 - TV)/\sigma_\varepsilon) - \rho(\eta/\sigma_\eta)}{(1 - \rho^2)^{1/2}}\right) \right] \\ &+ \sum_{i=1}^n I_1 \log \left[1 - \Phi\left(\frac{((t_1 - TV)/\sigma_\varepsilon) - \rho(\eta/\sigma_\eta)}{(1 - \rho^2)^{1/2}}\right) \right], \end{aligned} \tag{20}$$

where TV is defined in Eq. (8), and $\eta = \ln x - (\alpha + \beta p + \gamma q + \delta m)$, from Eq. (17). The variable I_1 is a dummy indicator for the discrete WTP response (1 for yes, 0 for no).

¹³Generally, when results from the SB and DB approaches differ, the SB is recommended as being less subject to bias from response incentive effects, and typically also generates higher WTP estimates. We examined the DB dichotomous choice WTP-demand model, and (as is often reported in the literature) its WTP estimates were lower than for the SB-demand model. Ninety-five percent confidence intervals for WTP did not overlap for the DB-demand and SB-demand models when weak complementarity was assumed, while they did overlap in the models with nonuse value.

¹⁴The conditional distribution of y given x has a normal distribution with mean $\mu_y + \frac{\rho\sigma_y}{\sigma_x}(x - \mu_x)$ and variance $(1 - \rho^2)\sigma_y^2$.

The distinctive feature of the likelihood function in (20) is that two behavioral responses—trips taken and responses to WTP questions—are derived from a unified underlying preference structure, allowing cross-equation restrictions on parameters of the recreation demand model and the WTP function. The parameters of (20) were estimated using the maximum likelihood module of GAUSS.

4. Data

The joint model of combined revealed and stated preferences is illustrated by a case study of the MKR basin located in Korea. The MKR originates inland in Cholla Buk Do province and is joined by several branch streams before reaching the Yellow Sea. The MKR provides irrigation water for agriculture in the province as well as recreational sites for a million people residing within the river basin. Recently, concern has been growing about deterioration of water quality of the MKR due to sewage and industrial waste water from urban areas, along with livestock manure and other runoffs from agricultural farms.

Water quality standards for surface waters in Korea follow a five-tier system. Class I water is considered drinkable when boiled. Class II is swimmable waters, and people would be safe swimming in the river. Class III water is fishable, in that game fish can survive in the water and be eaten without endangering human health. Water in Class IV is boatable, and people would not experience harm to their health if they fell into the river for a short time while boating. Water in Class V does not allow any of these activities [38].

Over the years, waters in the downstream reaches of the MKR have been graded to be Class V, which designates water quality not good enough even for agricultural use. Especially recently, water quality levels of the MKR have been at the center of a controversy associated with a large reclamation project, the Sae Man Kum Project.

The Sae Man Kum project is a large-scale reclamation project which is designed to construct a 33 km dike downstream of the MKR during the period 1991–2006. The completion of the dike is expected to create some 40,100 hectares (ha) of reclaimed land: agricultural land of approximately 28,300 ha and a man-made lake of some 11,800 ha. However, there has been outrage and apprehension that the man-made lake will be dead within just a few years if polluted water from the MKR, which is upstream of the lake, continues to flow into it. In response to those concerns, the government—at both local and federal levels—initiated cleanup plans to improve water quality of the MKR to the level of Class II (swimmable). Since the government anticipates that those plans will cost at least \$450 million,¹⁵ it is important to compare these costs with the value that residents in the river basin place on the water quality improvement.

To elicit economic benefits associated with the improvement of water quality in the MKR, an in-person household survey of residents along the MKR basin was conducted during October and November of 2000. This river basin encompasses four cities and one county across the Chonbuk province, which constitute the sampling areas. The sample of residents over 20 years old (excluding students) was allocated across the five sampling areas according to the age and gender distributions of each. Interviewers first screened respondents based on these criteria, and if the respondent met the desired criteria the interview continued. Cooperation rate (defined as the number of interviews that were completed once respondents met the screening criteria, was approximately 85%. This relatively high rate that is attributable in part to cultural factors, and resulted in a total of 510 usable surveys from users of the MKR. Information was collected on respondents' actual recreational use, their subjective perceptions and knowledge about water pollution of the MKR, contingent valuation questions for improved water quality and debriefing questions, and other economic and demographic characteristics.

4.1. Recreation demand and travel costs

To obtain revealed preference data associated with recreational use of the MKR, recreational participation and visit frequency for the previous year were elicited for six sites that stretched from upper tributaries to downstream reaches of the MKR. The main recreational activities enjoyed at those six sites are swimming, playing in the water, family picnics, and fishing. The six sites could be considered substitutes for each other but

¹⁵At the exchange rate (1300 won/US\$1) when the survey was conducted (November 2000).

are differentiated by water quality. Water quality of each site was matched with an objective quality indicator, the annual average biochemical oxygen demand (BOD) level,¹⁶ which is the amount of oxygen required to decompose organic material under specified temperature conditions.¹⁷ Respondents in the sample had visited at least one of the six sites along the MKR during the previous year, and were considered as users of the MKR and formed the sample for the empirical evaluation of our approach to combining data for estimation of the preferences that generate both types of responses.

As mentioned earlier, recreational activities enjoyed at each of the six sites are mainly swimming, playing in the water, family picnicking, and fishing, and thus the six sites were considered to be close substitutes for each other. Therefore, recreation demand functions were estimated based on the number of visits to a “typical site,” where the typical site is defined to be the site most frequently visited by a respondent¹⁸ [9,19]. To reflect the variation in the water quality variable among respondents, the annual mean of BOD for a respondent’s typical site was used as the water quality variable for that respondent. Also, the changes in water quality presented in the CVM questions (i.e., from Class V to Class II) were converted into changes in BOD levels.

As a price variable, travel costs were measured by the sum of the money and time cost of travel to the site.¹⁹ Round trip distance was measured from the map using respondents’ detailed residence information. The opportunity cost of time was assumed to be a fraction (30%) of respondents’ wages [10]. Respondents’ wage rates were calculated based on their occupation, which was elicited in the survey. The average wage of each occupation category was weighted by the respondent’s gender, education and experience.²⁰ Imputed hourly wages ranged from \$2.19 to \$22.17. The opportunity costs of housewives, students, and unemployed respondents were assumed to be zero. Household income was constructed as the sum of monetary income before taxes and the monetized time budget, using the assumed opportunity cost of time.

4.2. Willingness to pay for water quality improvement

Following questions eliciting respondents’ knowledge of, and subjective perceptions about, water pollution levels of the MKR, respondents were presented with a map of the MKR area in which each branch stream was depicted with different colors depending on its water quality level. After looking at the map, respondents were provided with up-to-date information about the MKR area, including water pollution levels downstream, causes of water degradation, and potential government policies to cleanup the river system. The status quo water quality level of downstream reaches was described to be worse than Class V according to the river water quality standards, with the additional information that no use for fishing, swimming, or other water contact was possible.²¹

Because of controversies among experts about whether the government policies would achieve the goal of improving water quality of the MKR to swimmable (Class II), the sample was divided into two groups that received different versions of water quality improvement levels. One treatment informed respondents that the

¹⁶The quantitative standards for maximum BOD levels corresponding to different classes of water quality are: 1 parts per million (ppm) (mg/l) for Class I, 3 ppm for Class II, 6 ppm for Class III, 8 ppm for Class IV, and 10 ppm for Class V [38].

¹⁷BOD is a widely used way of measuring surface water pollution levels. While dissolved oxygen (DO) might be a preferred measure of water quality in some settings, there are some advantages to using BOD. First, it is the water quality measure that the public is more familiar with since BOD levels are regularly reported to the public by the news media. Also, under the current water quality act in Korea, BOD levels provide a better distinction between the swimmable (Class II) and fishable (Class III) water quality levels. Consultations with environmental scientists indicated that BOD is a fairly good proxy for DO in the MKR region, since the region’s effluent is mainly organic wastes from residential wastewater as opposed to industrial discharges.

¹⁸This choice was made because of the definition of the water quality variable, which was an annual average of BOD. It would not be possible to identify quality parameters in demand that motivate site choices in a full six-site system, since there would be no variation in site quality across respondents.

¹⁹Most respondents in the sample spent about a half day at the sites they visited. Since there was not much variation in on-site time among respondents, we decided not to include their on-site time costs as part of travel costs.

²⁰Average wage by occupation and weights for gender, education and experience were based on “tables for average monthly wage by occupation, gender, and experience” in the 1999 Statistical Report for Wage Structure [39].

²¹Focus group participants found it easier to connect water quality standards with allowable activities than with BOD levels. To reflect this, the water quality ladder presented to respondents added the descriptions of allowable activities for each class of water.

Table 1
Definitions of variables and sample characteristics

Variable	Symbol	Description	Units	Mean	Std. dev.
Travel cost	p	Full price of a trip	\$	29.91	21.34
WQuality	q	Negative of BOD level matched with the most frequently visited site by each respondent	ppm	-6.75	3.61
Income	m	Households' before tax full income in 2000	\$000/mo	2.384	1.269
Memory	d	= 1 if respondents remembered swimming in the MKR in their youth; = 0 otherwise		0.4	0.5
Trips	x	No. of trips to most frequently visited site during the last year		3.84	9.50
Urban	D_2	= 1 if respondent resides one of three cities in the sample; 0 otherwise		0.63	0.48
Gender	D_3	= 1 if respondent is male; = 0 otherwise		0.48	0.50
Child	D_3	Number of children in the household		0.79	1.01
Bid1	t_1	Monthly charges for the 1st WTP question	\$	5.96	5.72
Yes1	I_1	Response to first WTP question (yes = 1, no = 0)		0.38	0.49
<i>Policy scenario variables</i>					
WQCV	q^0	Initial water quality downstream in the CVM scenario	ppm	10	
WQCV	q^1	Subsequent water quality in the CVM scenario	ppm	3 or 6	
WQD	$q^0 - q^1$	Quality improvement presented in CVM scenario	ppm	7 or 4	

government policy implementation would improve water quality downstream in the MKR to Class II (swimmable) levels, while in the other, water quality would be improved to Class III (fishable) level.

In addition to verbal explanations of the current and improved water quality levels, interviewers showed respondents a water quality ladder as a visual aid to help them understand the relative changes in water quality. In light of focus group responses and pre-test results, the payment vehicle chosen was monthly charges for water quality improvement as a specifically designed object tax, which would continue in perpetuity. After reminding respondents to consider their household income and expenditures (following the NOAA panel's recommendations), respondents were asked if they would pay the suggested monthly charges. In the experimental design, respondents were randomly assigned one of 10 bid values ranging from 75 cents to \$23 per month.

In jointly estimating the same parameters for WTP and demand, it is necessary for the time dimension of each to match. Since trips taken were on an annual basis, compensating variation measures from the demand function are annual measures. To match up the SP data with the RP data, annual WTP estimates are needed. These are obtained by using annual WTP bids (monthly WTP bids multiplied by 12) in the joint demand-WTP estimation.²²

Following debriefing questions to identify reasons why people did not wish to pay for improved water quality, respondents were asked to state which level of water quality they thought would be achieved (Class II or Class III) if the government policy programs were implemented. Table 1 defines the variables used in the analysis and provides summary statistics.

5. Results

Table 2 reports the results of the joint estimation of actual recreation demand and contingent WTP functions. To generate a specification that allows for the possibility of nonuse value, the nonuse parameter ψ was allowed to vary with individual characteristics, as $\psi = (\sum_k \psi_k D_k)^2$, where D_k is the k th demographic

²²Monthly WTP can be problematic for measuring total project WTP due to individual differences in discount rates and beliefs about project duration, among other factors, but the annual WTP bids used in estimation and annual WTP measures that result should not be so susceptible to this problem.

Table 2
Joint estimation of revealed and stated preference data

Variable	Symbol	Model	
		Nonuse value	Weak compl.
<i>Parameters common to demand and WTP</i>			
Intercept	α	−0.9534 (−8.13) ^a	−0.9044 (−7.67)
Travel cost	β	−0.0163 (−9.00)	−0.0160 (−9.37)
WQuality	γ	0.0235 (2.90)	0.0380 (5.91)
Income	δ	0.0526 (1.51)	0.0696 (2.22)
Memory	d	0.1725 (2.15)	0.2080 (2.64)
<i>WTP-only (nonuse value) parameters</i>			
Intercept	ψ_0	−0.1538 (−0.79)	0.0000 –
Memory	ψ_1	0.3158 (1.89)	0.0000 –
Urban	ψ_2	0.4928 (2.26)	0.0000 –
Gender*Child	ψ_3	0.2502 (2.91)	0.0000 –
<i>Standard errors</i>			
Demand	σ_η	8.8349 (8.63)	10.4301 (8.16)
WTP	σ_ϵ	0.9162 (31.37)	0.9076 (31.67)
Correlation	ρ	−0.1055 (−1.70)	−0.0911 (−1.51)
Mean log-L		−0.9928	−1.0070
Number of cases		510	510
χ^2 test statistic for $H_0: \psi = 0$			14.55
Critical $\chi^2_{0.05}(df)$			9.49 (4)

^aStudent's-*t* statistics in parentheses.

characteristic (with $D_0 \equiv 1$ so that ψ_0 is a constant). This specification imposes the requirement that nonuse value be nonnegative, which is justified both by theory and intuition.²³ Then the hypothesis of weak complementarity between demand and water quality changes was made, as a restricted version of the model with $H_0: \psi_k = 0 \forall k$.

Overall, most explanatory variables significantly influenced both trip demands and WTP functions with the expected signs. Travel cost had significant negative effects on both the number of visits to the typical site and on the probability of being willing to pay a given bid amount. Full income had a positive effect on demand and WTP, and was significant at the 5% level in the weakly complementary model and the 15% level in the nonuse value model. Water quality was highly significant in both decisions too; better water quality induced more frequent trips to the site as well as a higher probability of saying *yes* to the CVM question(s). Memory, a dummy variable with a value of 1 for respondents who had memories of swimming along the MKR in their youth, also was significant, with more frequent visits and a correspondingly higher use value for water quality improvements.

²³Eq. (16) shows that the restriction that $\psi \geq 0$ is the mild assertion that the quality change is not a bad when the individual is not consuming recreation trips. All the literature that discusses nonuse value presumes that it is nonnegative (e.g., [30,34,19]).

Table 3
Use value, nonuse value, and total value of water quality improvements (\$/year)

Welfare measure	To fishable level	To swimmable level
Total value	26.56 (4.67) ^a	47.64 (8.48)
Use value	16.35 (5.39)	29.78 (10.11)
Nonuse value	10.21 (5.60)	17.86 (9.79)

^aEmpirical standard errors from Krinsky–Robb [29] approximations are in parentheses.

Memory also was a significant explainer of the nonuse value term. Two other significant demographic factors were Urban, a dummy variable indicating residence in one of the three cities in the sample; and Child*Gender, where Child is the number of children in the household and Gender is a dummy variable indicating whether the respondent is male or not. A variety of other demographic shifters were explored for both the use and nonuse value parts of preferences, but none of these provided any greater explanatory power for either demand or WTP.

5.1. Tests for weak complementarity of preferences

As noted in Section 2, the test for weak complementarity is to evaluate whether the null hypothesis $H_0: \psi = 0$ holds within the model. The χ^2 test statistic for the likelihood ratio test of the restriction $\psi = 0$ is 14.55 (Table 2), which exceeds the critical $\chi^2_{0.95,4df}$ of 9.49. Thus, the hypothesis that preferences satisfy weak complementarity is rejected for this model.

5.2. The use and nonuse values of a water quality improvement

Based on the nonuse value models of Table 2, welfare measures of water quality improvement are presented in Table 3. The TV that users place on the water quality improvement is estimated for two policy relevant changes: the improvement to fishable level, a 4 ppm reduction in BOD, and to swimmable level (a 7 ppm reduction). Using Eqs. (14) and (15), TV estimates were decomposed into use values and nonuse values.

Annual total WTP to restore water quality to the fishable level was \$26.56. Standard errors were simulated based on the Krinsky–Robb approach using means of the covariates and 10,000 draws. Use value was \$16.35, while nonuse value was estimated to be \$10.21. All of these estimates are significantly different from zero at the 95% level (using a single-tailed test).

For improvements in water quality to the swimmable level, the total WTP was \$47.64, of which use value was \$29.78 and nonuse value was \$17.86. As with the improvement to fishable, all estimates are significantly different from zero.

The statistically significant nonuse value for river users is noteworthy. This should be interpreted as saying that the two valuation methodologies produce distinctly different estimates of the value of a water quality change by users of the MKR. When they are reconciled within a unified model of preferences, the nonuse value is the estimate of the magnitude of this systematic difference, and implies that MKR users include more than just their use value in their statements of WTP for water quality improvements. This is consistent with the fact that the revealed and stated preference approaches identify different parts of the value of water quality improvement.

6. Concluding remarks

This paper has developed and demonstrated a convenient, utility-theoretic approach to combine information from revealed and stated preference data in assessing the TV of environmental quality

improvements. The approach begins with a statement of behavior, via a demand function. Integrating back identifies the underlying quasi-expenditure function, in particular the preference parameters related to use and nonuse value. The quasi-expenditure function is used to define the compensating variation of a quality change, which is the WTP that individuals express in stated preference experiments such as contingent valuation.

This leads to a two-equation system that represents preferences for environmental quality, as expressed in both the individual's behavior and in their statements of WTP. Because the preference parameters pertaining to use value and to nonuse value are known, an exact decomposition of WTP into both use and nonuse value is possible. This decomposition is particularly useful in matching data collected by different methods for the same valuation problem, because the nonuse value component comes solely from the stated preference data, while the use value component comes from both stated and revealed preference data.

A notable feature of our modeling approach is that several hypotheses can be tested conveniently as parametric restrictions on the model. These include (a) whether weak complementarity holds, and (b) how nonuse value of users varies systematically with individual characteristics.

The method was applied to an important case study on the MKR system in Korea, where a public reclamation project affects water quality and, therefore, current users' recreation behavior and their WTP for water quality improvement. The preference parameters of MKR basin users relating to both recreation demand and WTP functions were recovered by jointly estimating revealed preference (travel cost) with stated preference (contingent valuation) data.

Relevant economic variables such as price (both travel costs and bid amount) and income had significant influence on both recreation demand and WTP for water quality improvement as anticipated by the economic theory. Water quality of the typical site for each respondent had significant impact on trip frequencies to the site, and the scope of water quality improvement conveyed in the CV question also had significant influence on respondents' WTP.

Comparing the model that allows for nonuse value with the model that does not, the hypothesis that recreation travel is weakly complementary with water quality was rejected. Annual total WTP for an improvement in water quality from status quo (unsatisfactory for agricultural use) to fishable and swimmable was \$27 and \$48. Use values (i.e., the part of these amounts accounted for by changes in demand) were \$16 and \$30, while nonuse value was \$10 for improvement to fishable and \$18 for improvement to swimmable. All these estimates are statistically different from zero. These results are, of course, dependent on our specification of preferences, which consists of both the nonuse term and the demand function.

The point of identifying the (use and nonuse) components of TV for users is to identify precisely how the two types of data must be matched in a given model of preferences. While it is interesting to note that users can demonstrate statistically significant nonuse value, as predicted by theory (e.g., [19]), the real significance is in helping to better understand systematically what is measured by revealed preference data and what is measured by stated preference surveys. When the two types of data are matched in a theoretically consistent and rigorous way, better statistical fits are possible because allowance is made for how value estimates from the two types of data might differ systematically, and more information is used in estimation.

The empirical application in this study was to users of the MKR because of the focus on combining stated and revealed preference data. The preference model, based on semilog demand, is consistent with this purpose. A natural generalization would be to estimate preferences for both users and nonusers, accounting for the participation decision. To do this, a demand model that allows for nonparticipation is needed. Given data on multiple demands or WTP for quality characteristics, utility-theoretic demand systems [11,44] can be used to identify and estimate the individual-specific nonuse values that explain differences between the revealed and stated preference data. Finally, while our specification is theoretically consistent in that the systematic parts of demand and WTP are traceable to the same underlying preferences, it is possible to improve on this by a more consistent treatment of error structure along the lines of the analysis by Dubin and McFadden [14].

Acknowledgments

We thank the editor and two anonymous reviewers for comments that helped clarify and sharpen our exposition, and Dan Lew for valuable additional insights, though any deficiencies are our responsibility alone.

This research was partially funded by the Korea Research Foundation (Grant KRF-2001-013-C00071) and research funds provided by Chonbuk National University.

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