# Benefit Transfer via Preference Calibration: "Prudential Algebra" for Policy

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ABSTRACT. *This paper proposes a new approach to benefit transfer. The method assumes a specific form for preferences and uses available benefit information to identify and calibrate the preference parameters to match the existing benefit estimates. This approach assures economic consistency of the transfers. Benefit measures can never be inconsistent with household income. The logic also offers a series of potentially observable "predictions" that can be used to gauge the plausibility of benefit transfers. When multiple benefit estimates from different methods are available such as hedonic property value, travel cost demand, and contingent valuation, the framework uses the definition of the benefit concept from each method in a single preference function to reconcile differences. It provides a specific way to take account of baseline conditions and scope effects (i.e., the size of the proposed change) consistently in the transfer. The method is illustrated using estimates for benefit measure changes in water quality from three studies: travel cost demand, hedonic property value, and contingent valuation analysis.* (JEL Q26)

## I. INTRODUCTION

For practical reasons, benefit transfer methods are commonly used to assess the economic values arising from environmental, natural resource, and other social policies. By offering a relatively low cost approach for assessing the benefits associated with proposed policies, these methods can help to meet the growing demand for the benefit component of benefit-cost analyses. However, as we discuss below, recent experience raises concerns about the appropriateness of conventional benefit transfer practices, particularly when they are applied to evaluate large scale policy changes.

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This paper proposes a new approach to benefit transfer, which is intended to address these concerns. Our method relies on a feature of all approaches for assessing the economic benefits (or losses) resulting from a change in either a price or in environmental quality. These methods have a conceptual foundation that is based on budget constrained utility maximization. Thus, when the economic structure assumed to underlie behavior is made explicit, by specifying a functional form for preferences and for all relevant constraints, each approach to benefit estimation will have a specific connection to that preference (i.e., utility) function. This logic has been a major influence on the micro-economics of consumer behavior (e.g., the development and testing of restrictions on systems of demand equations, see Deaton [1986]). At a general level, it is also the source of the integrability restrictions for consistent measurement of welfare changes from price and quality changes (see Ebert [1998]) and from partial demand models (see LaFrance and Hanemann [1989] and La-

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France [1990]). Unfortunately, this logic has generally not been a part of benefit transfer.

To address this shortcoming, we adopt a framework comparable to what is used to assess whether the information from a demand function is sufficient for welfare measurement (Hausman [1981]). In our case, we reverse the logic. We assume a specific form for preferences, and then ask whether the available benefit information is sufficient to identify the preference parameters. If preference parameters can be identified from the available benefit estimates, then the results define a valuation function that can be used to assess the benefits of a range of policy-related changes.[1]

There are at least four advantages to this strategy. First and foremost, it assures economic consistency of the transfers. The resulting benefit measures can never be inconsistent with household income, as they have been in some high profile applications (Constanza et al. [1997]). The method also defines a systematic way for adjusting transferred benefit estimates, to ensure that they are consistent with the other economic constraints on the individuals (or households) for whom they are being transferred. Second, the logic can offer some observable "predictions" that can be used to gauge the plausibility of benefit transfers. Third, when multiple benefit estimates are available from different methods, the framework uses the definition of each method's benefit measure within a single unifying preference function to reconcile differences. And finally, it provides a specific way to take account consistently of baseline conditions and scope effects (i.e., the size of the proposed change). To illustrate our strategy we use estimates from three different methods for measuring non-market benefits (i.e., travel cost recreation demand, hedonic property value, and contingent valuation) to calibrate a common preference function.

Extrapolating research results to new applications that they were not originally intended to represent is, by its very nature, a speculative process. As a result, some economists consider any approach to benefit transfer inappropriate. Unfortunately, this argument implicitly suggests analysts are incapable of learning from accumulated research experience. In one respect, benefit transfer follows Benjamin Franklin's call, over two hundred years ago, for informal benefit cost analysis using experience in other situations to evaluate net benefits for new circumstances as "moral or prudential algebra."[2] Our method imposes ground rules to assure the judgments made by different analysts for the same task or the same analyst for different tasks can be systematically compared and replicated. Thus, our approach takes Franklin's analogy to algebra seriously.

Section 2 provides some background on what benefit transfer is and why a revised approach to developing transfers is important. The next section outlines the basic logic for developing calibrated preference functions for benefit transfer. It presents a simplified form of our logic using three different estimates that were selected to provide overlapping benefit measures. We reconcile the differences among the estimates by describing how each benefit estimate relates to a common preference function. Section 4 discusses the calibrated estimates for our example with these three studies of the benefits for water quality improvements. Our example illus-

[1] It is important to note that this process requires different information depending on the measures available in the literature. If we have measures of a Hicksian willingness to pay for a discrete change in environmental quality for one study and estimates of the measures of the marginal willingness to pay from another, the process will be different than if we have a Marshallian consumer surplus for a quality change from one type of use and the Hicksian WTP for both uses and nonuse values.

[2] The citation to Benjamin Franklin was first called to our attention by Scott Farrow and Mitchell Small. Gramlich [1990] uses it to introduce his text on cost-benefit analysis without offering much context. Apparently Franklin developed the remarks Gramlich quotes, calling for "moral or prudential algebra," in a letter of September 19, 1772 that he wrote to Joseph Priestley. Priestly was troubled deciding about an offer of new employment.

In his book on Franklin, Campbell [1997] describes the source for Gramlich's quote and suggests that Franklin sought "to simplify the complexity of making decisions so that human well-being could be advanced." (Pg. 143) According to Campbell, Franklin was apparently careful to qualify that his call for prudential algebra was purely procedural—describing how to make decisions, not what to decide. Thanks are due Laura Bush for uncovering the sources for Franklin's quote.

trates the calibration logic. It is not intended to imply that our calibrated function should be used in future benefit transfers. In section 5, we outline an adaptation to our proposal that could be used if more benefit estimates were available. The last section discusses how our proposal might be evaluated.

## II. BACKGROUND

Benefit transfer generally refers to the practice of taking and adapting value estimates from past research (e.g., values for a change in an environmental resource) and using them (hence the term ''transferring'') to assess the value of a similar, but separate, change in a different resource (e.g., a comparable environmental resource). Nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not. Two steps generally summarize the computation of benefits:

1. estimate, usually in physical terms, the consequences of the proposed regulatory action, new public investment project, accidental release of hazardous materials, etc.; and
2. multiply each component of these computed physical changes by a unit value assumed relevant to the category that is expected to change.

The transferred unit value describes the benefits (in dollars) that are gained or lost for each unit of the physical change. As such, the unit value serves a role that is analogous to a ''price.'' Most benefit transfers utilize either the benefit value or the benefit function approach. The distinction between the two approaches arises from what is used for the unit value. A benefit value approach uses a single point estimate to define the unit value. Thus, for example, an estimate of the average consumer surplus per fishing trip associated with specific water quality conditions at one location might be used to evaluate the benefits from use when these improved water quality conditions are experienced at a new location. The derived pre-trip value is multiplied by the number of trips estimated for the improved water quality conditions to estimate the fishing benefits of the new water quality conditions. The benefits attributed to the old conditions are then subtracted from this estimate to measure the gain from the change.

Benefit functions are usually statistical models describing how the estimates of unit values vary with changes in the economic and demographic characteristics of the people studied. These functions are reduced form equations that often do not impose the restrictions implied by budget constrained utility maximization. These functions can be used to tailor the unit values to the economic and demographic characteristics of the population in the transfer application.

Both approaches involve implicit assumptions. First, benefit values are used as if the marginal willingness to pay for the quantity or quality change were locally constant. Second, to the extent that the unit value is defined in terms of a specific use (i.e., fishing days) or an impact avoided (i.e., avoided sick days), then multiplying the unit value by the amount of use (or impact) also incorporates an implicit assumption about the relationship between the environmental amenity and the measured use. This condition could imply a minimum quality level is required for a fishing day and that higher levels would not lead to greater gain. Finally, when estimates are added up across different categories of impacts, the analysis usually assumes separability in how each category of effect contributes to a consumer's well being.

The literature to date contains little specific guidance on how to evaluate the multiple judgments associated with transfers. The best overall summary of what has been learned about these methods over the past decade is reflected in a common conclusion reached by all recent evaluations of benefit transfer—*the conventional approaches are very unreliable!*[3] As we noted at the outset,

[3] Recent studies evaluating transfers include an increasing array of studies (e.g., Loomis et al. [1995], Downing and Ozuma [1996], Kirchoff, Colby, and LaFrance [1997], Brouwer and Spaninks [1999] and Santos [2000]). For different nonmarket commodities, each of these studies compares values estimated directly through nonmarket valuation techniques (e.g., contingent valuation) with values estimated using a transferred study. Transfers are generally interpreted to be ''valid'' or ''reliable'' if the estimates are not statatisti-

this leads many academic economists to conclude it should not be done. Unfortunately, this conclusion fails to appreciate how analysis enters the policy making process.

Any approach for evaluating the benefits of a new policy will have errors. Even if we were able to develop new benefit research for each new policy and tailor that work to fit the affected area, it would not provide "perfect" estimates. Therefore, the "convergent validity" tests conducted in the literature do not offer an irrefutable standard of performance for benefit transfers. Equally important, the timing and resources available to support the policy process preclude the development of new studies. As a result, the choice is not between a new study or a transfer but between transfer and qualitative judgment. Finally, nearly all uses of micro-economics for policy involve a logic that is comparable to transfers. That is, when estimating the price or tax revenue changes due to a new sales tax, one must assume specific demand and supply elasticities. The change may imply prices outside the range of observed experience. These cases differ from benefit transfer because we can observe, after the fact, what happened. With benefit measurement, for non-market resources, the concept being estimated is never observed. This feature is one motivation for a framework that provides other observable "predictions" that can be compared with actual experience after a policy has been implemented.

The fact that transferring benefits often requires extrapolation outside the range of previous experience supports the need for more defensible practices. Extrapolation arises any time a unit benefit, $\tilde{p}$, is multiplied by a change in some output provided by the action under study, say a $\Delta q$, that is outside a small range. Moreover, to the extent we interpret $\tilde{p}\Delta q$ as a measure of what one would pay for such a change, this implies that the income needed to make the payment is available. We expect that the initial level of $q_0$ as well as the size of the change ($\Delta q$) would affect the magnitude of the gains realized from the increase. Unfortunately, none of the approaches currently used in benefit transfer allow these consistency restrictions to be incorporated.

As the scale of the change becomes large, it is important to assure that the benefit (i.e., willingness to pay) measure for the improvement takes into account the income available. Failure to impose this consistency has been a source of criticism of two recent high profile studies. The Costanza et al. [1997] evaluation of the annual value of the earth's primary ecosystems implied a willingness to pay that exceeded the authors' own estimates of the income available to pay this measured willingness to pay.[4] While this study made the disparity quite apparent through the way the authors chose to report their findings, other studies are more difficult to evaluate in these terms. EPA's recent Retrospective Analysis of the net benefits from air quality improvements between 1970 and 1990 (U.S. Environmental Protection Agency [1997]) is one such example. This EPA study compares the observed time profile (1970–1990) of air quality with an estimate of what this profile would have been without the regulations, and it estimates the aggregate value of the difference. The resulting "asset" measure was 22 trillion dollars (in 1990 dollars), approximately the net worth of all U.S. households in 1990 (Lutter and Belzer [2000]) and about three times gross domestic product. The annualized values of the gain, at the household level, are about 25% of income. Both of these comparisons suggest the failure to impose the discipline of a budget constraint could be an important concern in this case as well.

## III. THE LOGIC OF CONSISTENT BENEFITS TRANSFERS: CALIBRATED PREFERENCE FUNCTIONS

The linking of available benefit measures to a preference function involves four steps:

1. specify a "representative" individual's preference function;

cally different from one another; however, in most applications this test of convergent validity is rejected. Recent reviews of the practice of transfer are also given in Bergstrom and De Civita (1999) and Brouwer (2000).

[4] See Bockstael et al. (2000) and Pearce (1998) for further discussion.

2. derive a relationship between each available benefit measure and the preference function;
3. adapt the information to assure the variables assumed to enter the preference function are consistently measured across each study and linked to preference parameters; and
4. calibrate the preference function using these benefit measures.

To illustrate the basic idea in general terms, suppose equation [1] defines an indirect utility function.

$$v = V(\mathbf{p}, m, d, \boldsymbol{\gamma}), \quad [1]$$

with

$\mathbf{p}$ = vector of prices (with $P_i$ the $i$th good's price)
$m$ = household income
$d$ = environmental quality measure
$\boldsymbol{\gamma}$ = parameter vector.

Roy's identity relates Marshallian demand for $X_i$ to this function as in [2]

$$X_i = -\frac{V_{P_i}}{V_m} = f(\mathbf{p}, m, d, \boldsymbol{\gamma}). \quad [2]$$

Once we specify a function for $V(\cdot)$, then there will be a link between the parameters of $f(\cdot)$ and those in $V(\cdot)$. Depending on the functional form, we are often able, as noted earlier, to identify enough about $V(\cdot)$ to measure Hicksian surplus for price changes.

Our argument maintains that, for consistent transfers, we need to assume a specific function describing $V(\cdot)$ and use it explicitly to interpret the available benefit measures. Suppose then we have available a measure of the benefits of a change in $d$ (from $d_0$ to $d_1$). Equation [3] defines the Marshallian surplus (MCS) for the quality in terms of the demand equation given in [2], assuming $X_i$ and $d$ are weak complements.[5]

$$\mathrm{MCS} = \int_{P_i}^{P_i^{cc}} f(P_i, \bar{p}, m, d_1, \boldsymbol{\gamma})\, dP_i - \int_{P_i}^{P_i^{c}} f(P_i, \bar{p}, m, d_0, \boldsymbol{\gamma}) dP_i. \quad [3]$$

In this development, we have separated the $i$th good's price, $P_i$, from the vector $\mathbf{p}$ and relabeled the remaining prices as $\bar{p}$. $P_i$ is the existing price, $P_i^c$ and $P_i^{cc}$ are the Marshallian choke prices at $d_0$ and $d_1$, respectively.

Our calibrated transfer asks how much could we learn about the structure of $V(\cdot)$ when estimates of MCS are available? To address this question with many different estimates of MCS, each derived under different maintained assumptions for its demand function, we propose that an approximation be imposed. That is, all benefit measures in a particular transfer application are assumed to arise from a single preference function. We know the selected function will not be consistent with all the demand functions in the literature that, in turn, provide the benefit estimates for the transfer. Nonetheless, we adopt one form to impose consistency. This approach is important for another reason. Benefit estimates for improving $d$ do not come from a single type of study. They can be derived from contingent valuation, hedonic property value, travel cost recreation demand, and averting behavior models. To consistently calibrate, the benefit measure available from each model needs to be defined in specific terms and that definition used to relate each measure to the same preference function.

Selecting one functional form for preferences is the compromise that allows estimates from diverse sources to be included consistently. Using a single preference function allows each method's estimate of benefits to reveal some aspect of a "representative" individual's preferences for environmental resources. We are unable in this setting to match the specific preference function implied by any particular application.[6] In our example we also do not include unobserved heterogeneity in preferences.

[5] Weak complementarity implies that the economic value of changes in $d$ would be zero when an individual did not consume a positive quantity of $X_i$.

[6] In most demand applications we have incomplete demand systems that must be restricted to satisfy integrability conditions if the link to quasi preferences is to be established. Few applications actually impose these conditions. See LaFrance and Hanemann (1989), LaFrance (1990), and Von Haefen (2000) for more details.

There is no reason this extension could not be considered. At present few of the benefit estimates have enough information to support this extension. However, with continued research, taking account of how unobserved heterogeneity affects consumer preferences, it should be possible to accommodate this generalization.

*Step 1: Specify the Preference Function*

To develop our example we selected benefit estimates for water quality changes from measures available using contingent valuation, travel cost, and hedonic methods. Preferences are represented with a simple function given in equation [4] below. The form is a variation on constant elasticity of substitution (CES) specification, using a Cobb-Douglas sub-function to describe on-site demands for water quality. Quality is specified to enter two ways. First, to capture recreation-based values, a cross-product repackaging form (Willig [1978], Hanemann [1984]) is used. In effect, this specification treats water quality as if it reduces the per-trip cost of recreation. Second, water quality is assumed to make a separable contribution to utility with the term $(\theta_1 d)^b$. Ordinarily, we would not be able to observe this effect, but we also assume that there is information about a consumer's choice of a residential location. This added information allows the effect to be measured.

The function was selected because it is well-behaved (Varian [1992]), and has been shown by Quigley [1982] to allow the preference parameters to be recovered from estimates of a hedonic price function.[7]

$$V = (\theta_1 d)^b + \sum_{i=2}^{K} (\theta_i A_i)^b + [(P - h(d))^{-\alpha}(m - R(d, A_2, \ldots, A_K))]^b. \quad [4]$$

$P$ is the round-trip travel costs, $m$ is annual household income, and $\alpha$, $\beta$, $b$, and the $\theta_i$'s are parameters. $h(d)$ is a function that describes how the level of water quality, $d$, reduces the effective price of a trip. $R(\cdot)$ is the hedonic housing price function, expressed as an annual rent. It reduces the amount of income available for other uses. It is assumed to be a function of water quality, $d$, as well as a number of other housing attributes, represented by the $A_i$'s. The terms $(\theta_1 d)^b + \sum(\theta_i A_i)^b$ recognize that the housing attributes make contributions to an individual's utility. In particular, water quality improvements have a dual role. They contribute to someone who lives near a water body, and they also contribute to those (including the person living near the lake) who participate in recreation. If we wish to assume water quality has different levels at the recreation sites and at the residential location, then two $d$'s would enter the indirect utility—one for water bodies near a person's home and another $d$ assumed to represent water quality at the recreation site.

*Step 2: Derive a Relationship Between Available Benefit Measures and the Preference Function*

To illustrate how each type of benefit measure must be related to the specific preference function we selected three studies measuring the benefits of water quality improvements at fresh water bodies: (a) travel cost recreation demand model; (b) a contingent valuation analysis; and (c) a recent hedonic property value study. Some of the primary features of the three studies we selected for the numerical example are summarized in Table 1.

The recreation demand estimates were taken from Englin, Lambert, and Shaw [1997]. This travel cost study was selected because it included water quality changes that could be expressed in terms comparable to those of the well known Mitchell-Carson contingent valuation study. The Englin, Lambert, and Shaw travel cost recreation demand model has two components. One component links water quality, measured using dissolved oxygen (DO) concentrations (in mg/L), to total trout catch in New England lakes. These catch models were then used in the second component that describes recre-

[7] All individuals are assumed to have the same preferences.

TABLE 1
KEY FEATURES OF THREE STUDIES USED TO CALIBRATE PREFERENCES

| Studies Used | Mitchell and Carson | Englin et al. | Boyle et al. |
|---|---|---|---|
| Valuation method | CV | TC | Hedonic |
| Study area | National | New England | Waterville, Maine |
| Study size | 564 respondents | 1144 anglers | 112 houses[a] |
| Average income | $24,220 (1983$) | $36,060 (1989$) | $77,388 (1995$) |
| Water quality measure | "Use-support" category (i.e., dissolved oxygen (mg/l) boatable, fishable, swimmable) | | secchi depth (m) (in meters, m) |
| Water quality range evaluated | Below-boatable to fishable[b] | All waters achieve 5 mg/l | 4 to 6.3 m (mean = 4.13) |
| Average property price | | | $85,880 |
| Travel cost | | $20.40 per trip | |
| Welfare measure | Hicksian WTP | Change in Marshallian consumer surplus | Marginal price |
| Welfare estimate | $186 per household per year (for below-boatable to fishable increment) | $29 per season[c] | $1743 per meter |

[a] Other locations evaluated in this study included an additional 137 homes.
[b] An additional increment from fishable to swimmable was also evaluated in their study but is not included in this calibration example.
[c] Evaluated from 2.0 mg/l to 5.0 mg/l of DO.

ationists' demand for fishing trips. The authors report the average consumer surplus for improvements in dissolved oxygen for a set of lakes used by residents of New York (excluding New York City), New Hampshire, Vermont, and Maine during 1989. The benefit computation reported in their paper involves an increase in water quality for the poorest lakes to a minimum DO level of 5.0 mg/liter.[8] This scenario is somewhat similar to the framing used in the Mitchell-Carson contingent valuation question which asks about improving water quality in water bodies throughout the United States.

The contingent valuation estimate comes from Mitchell and Carson's 1983 national survey (reported in Mitchell and Carson [1984], [1986], Carson and Mitchell [1993]). This survey estimated people's willingness to pay to undertake policies that would incrementally improve water quality of the nation's water quality from below-boatable conditions to fishable conditions.[9] For the purposes of this illustrative example, we use the increment from below-boatable to fishable conditions.

The third study used for calibration is a hedonic property value study for recreational homes in Maine. The results are summarized in a study by Boyle, Poor, and Taylor (1999). This hedonic study focuses on the relationship between water quality and property values for homes around a set of lakes. The estimated price equation indicates that water clarity (as measured by secchi depth in meters [m]) has a significant positive effect on property values.

Each of these studies yields a different conceptual measure of the benefits due to water quality improvements. The Englin et al. results measure the change in Marshallian consumer surplus associated with improvements in dissolved oxygen levels through their effects on the catch rates for trout. The benefits are measured by describing the role of these catch rates for the demand for fish-

[8] They indicate that dissolved oxygen ranged from 0.88 to 11.94 mg/liter in their lakes with a mean of 3.4 mg/liter. 38 of the 61 lakes used in their sample had dissolved oxygen below 6.0.

[9] Mitchell and Carson's question offers an improvement "where 99% or more of the freshwater bodies are clean enough so game fish like bass can live in them" (Mitchell and Carson [1989], 385). Other water quality increments were also offered in their study; however, we only use their results over this increment to illustrate the calibration logic, since it is most directly comparable to the water quality changes considered in the travel cost and hedonic studies.

ing trips. The Mitchell and Carson (1986) CV study estimates Hicksian willingness to pay for discrete water quality improvements that are described in terms of a graphical scale, the water quality ladder. This graphic connects water quality to different types of water-based recreation that can be supported as a result of each of the specified improvements. The Boyle, Poor, and Taylor (1999) hedonic model yields an estimate for marginal willingness to pay for changes in water quality that enters the price function in terms of water clarity. Table 2 summarizes how the different valuation methods and measures from the three studies can be linked to the preference function given in equation [4].

*(a) Link Marshallian consumer surplus from the travel cost study.* The Englin, Lambert, and Shaw (1997) travel cost recreation demand function is a Marshallian demand. Using Roy's identity from equation [2] we can link it to the indirect utility function in [3]. The result is equation [5].

$$X_1 = \frac{\alpha(m - R(\cdot))}{(P - h(d))}. \qquad [5]$$

We used these authors' estimates for the Marshallian consumer surplus for a given water quality change (MCS). To define this measure in terms of preference parameters, we start with equation [5] and integrate this function with respect to price from the existing travel cost ($P_0$) to an upper limit ($P^c$). This process yields equation [6]:

$$\begin{aligned} \text{MCS} &= \alpha(m - R(d, A_2, \ldots, A_K)) \int_{P_0}^{P^c} \frac{1}{(P - h(d))} dP \\ &= \alpha(m - R(d, A_2, \ldots, A_K)) \ln(P - h(d))|_{P_0}^{P^c}. \end{aligned} \qquad [6]$$

Evaluating this definite integral yields equation [7]:

$$\begin{aligned} \text{MCS} = \alpha(m &- R(d, A_2, \ldots, A_K)) \\ &[\ln(P^c - h(d)) - \ln(P_0 - h(d))]. \end{aligned} \qquad [7]$$

We can use equation [7] to describe how the consumer surplus changes with a small change in water quality. The relationship is given by differentiating equation [7] with respect to water quality ($d$), as in equation [8].[10]

$$\begin{aligned} \frac{\partial \text{MCS}}{\partial d} &= \alpha(m - R(d, A_2, \ldots, A_K)) \\ &\times \left[ -\frac{h'(d)}{(P^c - h(d))} + \frac{h'(d)}{(P_0 - h(d))} \right]. \end{aligned} \qquad [8]$$

We selected this transformation because it provides a benefit measure that most closely aligns with what Englin et al. report in their paper. This adaptation is important because, in practice, published studies will often report benefit measures defined to correspond to an illustrative problem. They are not necessarily in a form that is easily linked to a preference function with a small number of added assumptions. Thus it can be important to consider further simplifications to this expression to economize on the information needed for calibration. The first term on the right side of equation [8] is the product of demand for angling trips at the choke price ($P^c$) times ($-h'(d)$). The second is the quantity demanded at $P_0$ multiplied by $h'(d)$. The definition of the choke price implies the first term should be zero.[11] Rearranging terms and using the demand function given in equation [5] we have an expression for per-trip marginal consumer surplus (with respect to $d$):[12]

[10] It is important to recognize that this specification implies income is net of the expenditures on housing, in our case the annual rent (i.e., $m - R(\cdot)$). As a result, measures of the change in the Marshallian consumer surplus (per recreation trip), due to a change in water quality, must also consider whether the rent is assumed to change when the water quality changes. We assume it does not. This approach is equivalent to assuming that adjustment in the rental market does not affect the disposable income relevant to an individual's observed recreation trips.

[11] The demand implied by preference function does not have a finite choke process. That is, setting $X_1 = 0$ in the demand panel in Table 1 and solving for $P$ does not yield a finite choke price. This is not especially important for our example. We assume there is some large finite value specified for the choke price.

[12] We interpret $(\partial MCS/\partial d)/X_1$ as the Marshallian surplus estimate for the water quality change as described by Englin, Lambert, and Shaw (1997), that is, increasing dissolved oxygen at the worst lakes to approximately fishable conditions—6.0 mg/liter. We used the estimated trips with improved water quality (5.06 trips per season based on Englin et al.'s [1997] for fishable conditions).

TABLE 2

LINKS BETWEEN MEASUREMENT TECHNIQUES AND A COMPOSITE CES/COBB DOUGLAS PREFERENCE FUNCTION

| Method | Benefit Scenario in Literature | Link to Preferences | Equation used for Benefit Measure | Interpretation of Literature for Identification |
|---|---|---|---|---|
| Travel cost recreation demand | Improvement in water quality that impacts recreational fishing | Roy's identity to define demand for recreation trips | $X_t = -\frac{V_P}{V_m} = \frac{\alpha(m - R(\cdot))}{(P - h(d))}$ | Assumes increment to Marshallian consumer surplus (MCS) with water quality change is based on net income with rents associated with baseline water quality |
| Contingent valuation | Improvement in water quality from below-boatable to fishable conditions | Definition of Hicksian willingness to pay | $\text{WTP} = m - R(d_0, \ldots) - \frac{[(\theta_1 d_0)^b - (\theta_1 d_1)^b + (P - h(d_0))^{-\alpha}(m - R(d_0, \ldots))]^b]^{1/b}}{[P - h(d_1)]^{-\alpha}}$ | Assumes respondents to contingent valuation question would treat their rents (or property values) as fixed with water quality improvement |
| Hedonic property value | Incremental willingness to pay for water quality change at a lake (slope of hedonic price function) | Assume hedonic price function is an equilibrium condition; increment to price equals marginal rate of substitution | $\frac{\partial R}{\partial d} = \frac{\partial MCS}{\partial d} + \frac{\theta_1(\theta_1 d_1)^{b-1}}{(P - h(d_1)^{-\alpha b}(m - R)^{b-1}}$ | Assume hedonic price functions do not change with any policy induced change in water quality |

$$\frac{\dfrac{\partial \mathrm{MCS}}{\partial d}}{\dfrac{\alpha(m - R(d, A_2, A_3, \ldots, A_K))}{(P_0 - h(d))}} = \frac{\dfrac{\partial \mathrm{MCS}}{\partial d}}{X_1} = h'(d). \qquad [9]$$

To complete the process of linking the available measure of the Marshallian consumer surplus to our preference specification, we need to define $h(d)$, the function describing how water quality reduces the travel cost of a recreation trip. For our example we selected the relationship, described in equation [10], a power function with the parameter, $\beta$, treated as an unknown constant.

$$h(d) = d^{\beta}. \qquad [10]$$

To apply this relationship in equation [9] and solve for $\beta$, we need to approximate $h'(d) = \beta d^{\beta-1}$. This can be accomplished through a series approximation, $\beta d^{\beta-1} \approx \beta[1 + (\beta - 1)\log(d)]$. $\beta$ can be solved as one of the roots of a quadratic equation.[13]

*(b) Link the hedonic study.* Our preference specification addresses a dilemma (posed by McConnell [1990b] and Parsons [1991]) that arises when environmental quality not only contributes to recreation demand but also serves as a site specific amenity contributing to housing values. By specifying $d$ as jointly contributing to *in situ* recreation and to the amenity values of a residence, this ''jointness'' must be resolved to interpret correctly the results from a hedonic model. That is, the marginal willingness to pay for a water quality improvement derived using a hedonic property model will overlap with the marginal value of water measured from a travel cost demand. Another way of describing this connection is to suggest that when an enhanced level of environmental quality increases the attraction of a residential location, it is also likely to enhance certain recreational opportunities.

McConnell [1990] concludes that when the sole motive for living near the resource is access to recreation, then both the travel cost and hedonic property value models measure the economic value for the same concept of access or enjoyment of improved water quality.[14] However, if there are several ways people can use enhanced amenities, then we would expect the consumers will select the mix to achieve the desired level of amenities for the least cost.

The specification for our preference function in equation [4] implies there are two ways an improvement in water quality ($d$) affects people. Enhanced water quality ($d$) at the recreation site reduces the effective price of recreation, and water quality contributes to individual well-being through the separable term, $(\theta_1 d)^b$, in the preference function. We evaluate this latter term through a person's choice of a residential location.

Differentiating equation [4] with respect to $d$, we can develop an expression for the relationship between the marginal rental price and the marginal willingness to pay for improvements in water quality ($d$). Our expression makes several important assump-

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[13] This assumption was deliberately complex to illustrate how approximations can be used to simplify matters and economic plausibility can help in the calibration. If we have selected a simple form (or if the ''true'' relationship that relates a technical measure of environmental quality to an index that describes how consumers perceive it had a simple form), then the solution could involve less detailed algebra. For example, if $h(d) = \delta \ln(d)$ (instead of $d^{\beta}$) then $h'(d) = (\delta/d)$. The solution for $\delta$ in this case in given in the following equation:

$$\hat{\delta} = d \cdot \left( \frac{\dfrac{\partial MCS}{\partial d}}{X} \right).$$

[14] Given that consumers can fully adjust, along with the assumption that water quality is only valued because of its effect on recreation, the two approaches should yield the same results in annualized terms. This statement assumes that the same consumer surplus concept (e.g., Marshallian versus Hicksian) is being used. The condition is a description of the consumer's marginal conditions for a maximizing utility subject to constraints. In this case water quality improvements can be obtained through adjustments in housing or recreation choices. There will be no further opportunity for improvement if the marginal gains realized through housing choices exactly equal the marginal gains available through recreation site choices.

tions. We assume the change in water quality is small so that equilibrium rent schedule does not change. The rent function, $R(\cdot)$, included in equation [11] describes an equilibrium. Large changes would imply a new equilibrium and potentially a different function. Our evaluation considers a small change in $d$ evaluated at the point where there are no gains from further re-location. This condition explains the last equality with zero.

$$\begin{aligned}\frac{\partial v}{\partial d} &= \theta_1 b(\theta_1 d_0)^{b-1} \\ &\quad - b\cdot(-\alpha)\cdot(P-h(d_0))^{-\alpha-1}\cdot h'(d_0) \\ &\quad \cdot(m-R(\cdot))[P-h(d_0))^{-\alpha}(m-R(\cdot))]^{b-1} \\ &\quad - b\cdot\left(\frac{\partial R}{\partial d}\right)\cdot(P-h(d_0))^{-\alpha} \\ &\quad \cdot[(P-h(d_0))^{-\alpha}(m-R(\cdot))]^{b-1}=0. \qquad [11]\end{aligned}$$

Re-arranging terms and using the expression for $\partial MCS/\partial d$ from equation [8], together with the assumption that these functions are evaluated at a baseline level of water quality, $d_0$, yields equation [12]. We used subscript ($0$) with the variable ($d$) for water quality in equation [12] to indicate that we have to select a level of water quality to use in evaluating the relationship. This level may well be different across the studies providing benefit estimates and therefore it must be treated consistently in each component.

$$\frac{\partial R}{\partial d}=\frac{\partial MCS}{\partial d}+\frac{\theta_1(\theta_1 d_0)^{b-1}}{(P-h(d_0))^{-\alpha b}(m-R(\cdot))^{b-1}}. \qquad [12]$$

The right side of [12] defines the change in the marginal value of access to improved water quality at an individual's home. Because we specified two roles for $d$ in preferences the marginal hedonic rent $\partial R/\partial d$ sums up the change in the recreation value with $d$ and the marginal value due to the aesthetic benefits. If preferences had omitted the $(\theta_1 d)^b$ term, then both the hedonic and the recreation demand model would provide information about the same use related benefits, that is, the first term on the right side of equation [12]. That is, the second term on the right side of [12] would be zero, and $\partial R/\partial d$ would only yield information about the value of changing $d$ that is realized through recreation use. This conclusion is the point of McConnell's analysis. Our algebra simply illustrates how it works for this application.

*(c) Link the CV study.* To complete our example we have assumed that information from a CV study of a water quality change is also available. Using it for calibration requires that we define how the willingness to pay for the water quality change posed in Mitchell and Carson survey questions relates to the common preference function. WTP for a water quality improvement, $d_0$ to $d_1$, is defined in equation [13]. It is the maximum amount of money that can be taken away from an individual when the water quality improvement (from $d_0$ to $d_1$) is provided.

$$\begin{aligned}(\theta_1 d_0)^b &+ [P-h(d_0))^{-\alpha}(m-R(d_0,\ldots,A_k))]^b \\ &+\sum_{i=2}^{K}(\theta_i A_i)^b=(\theta_1 d_1)^b \\ &+[P-h(d_1))^{-\alpha}(m-R(d_0,\ldots,A_k) \\ &\quad -WTP)]^b+\sum_{i=2}^{K}(\theta_i A_i)^b. \qquad [13]\end{aligned}$$

Having established this linkage between WTP and the preference function, it can now be used, along with the travel cost and hedonic results, to complete the identification of the preference parameters.

*Steps 3 and 4: Adapt Information from the Studies and Calibrate the Preference Parameters*

Calibrating the preference parameters using the relationships defined above requires that information on water quality, individual income, travel costs, housing prices, etc. be appropriately selected from the three studies and adapted, as necessary, to ensure compatibility. For example, all dollar values were converted to 1995 dollars using the consumer price index (CPI).

We begin by calibrating $\beta$ from the function adjusting the effective travel cost for water quality. To do this we use information from the travel cost study. Note that equation [9] can be re-written as equation [14] below and solved for the roots.

$$\frac{\partial MCS/\partial d}{X_1} = \log(d) \cdot \beta^2 + (1 - \log(d))\beta. \quad [14]$$

In this equation, the marginal consumer surplus, number of trips and water quality level (expressed in units of DO) are evaluated at the midpoint of the water quality range evaluated in the Englin, Lambert, and Shaw (1997) study. That is, with $d = 3.5$, $X_1 = 4.75$, then $\partial MCS/\partial d = \$12.1$.[15] The roots to equation [14] generate two potential solutions. Discriminating between them based on their economic properties, we calibrate $\hat{\beta} = 1.462$.[16]

Given an estimate for $\hat{\beta}$, and thus the $h(d)$ function, we can now calibrate the value of $\alpha$ by rearranging equation [5] and applying information from the travel cost study to the resulting equation

$$\alpha = \frac{X_1(P - \hat{h}(d))}{(m - R(\cdot))}. \quad [15]$$

This process requires we select consistent values for the trips ($X_1$), travel cost ($P$), water quality ($d$), income ($m$) and rent. Consistency in this context means that the value used for trips should be consistent with the travel cost, level of water quality, and income net of rent in the study furnishing this estimate. As in the previous equation, the water quality and number of trips are evaluated at the midpoint of the water quality range evaluated in the Englin et al. study. We approximate these conditions using the mean round trip travel cost ($P$) of \$25.6 and the mean income net of rent ($m - R$)—\$26,522.[17] As a result, we calibrate $\hat{\alpha} = 0.0035$.

The marginal WTP from the hedonic study and the CV estimate for WTP used in equations [12] and [13] allow the remaining parameters, $\theta_1$ and $b$, to be calibrated from these two studies. With these last two parameters derived from the available information, we have a complete identification of the parameters of this preference function. Because of the non-linearity of both equations we cannot, however, analytically solve for $\theta_1$ and $b$. A variation on the concept defining a numerical bisection solution is used with two remaining equations to recover the two remaining unknown parameters.[18]

Rearranging equation [12], which captures the housing choice equilibrium, generates the following expression for $\theta_1$:

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[15] Englin, Lambert, and Shaw (1997) estimate an increase in consumer surplus of \$29 (1989\$) and an increase in trips from 4.44 to 5.06 resulting from an increase in minimum DO to 5.0 mg/L. The initial level of water quality is assumed to be 2.0 mg/L for this calibration example.

[16] Had we selected the second specification for $h(d)$, such as expressing it in logarithmic terms—$h(d) = \delta \ln(d)$ the estimate for $\delta$ would be much simpler as we have noted in equation [10]. We adopted the more complex route to illustrate that non-economic functions can introduce the prospects for multiple solutions. Nonetheless, it is often possible to discriminate between them based on economic criteria. That is, by evaluating what the solutions imply for calibrated preferences we can sometimes eliminate one of them. This strategy has long precedent. Becker's (1964) computation of the rate of return to education relies on only one positive root to a high order polynomial in his definition of the internal rate of return to education. In that case Descartes rule of signs assured, for a specific temporal ordering of the size of annual benefits and costs, the existence of only one positive root.

[17] Englin and Lambert (1995) report travel costs of \$20.42 and average annual household income of \$36,060 (in 1989\$) for the same sample. Rent was assumed to be 41.3% of annual income.

[18] Numerical bisection uses the intermediate value theorem to compute solutions for a continuous function, $f(x)$, that can be expressed for different values of $x$ as follows:

$$f(a_0) < 0 < f(a_1), \text{ with } a_0 < a_1.$$

In our case we use a specific form for the indirect utility function to express how an estimate of each benefit concept, say $\hat{B}$, relates to each preference parameter (conditional on values of other preference parameters), $\theta$, to be calibrated. If this is written as $B = g(\theta)$, then setting $g(\theta) = \hat{B}$ implicitly defines an equation that allows solution for $\hat{\theta}$. To solve for $\theta$ we can consider values where $g(\theta_1) > \hat{B}$ and $g(\theta_2) < \hat{B}$. Rearranging terms we have the basic forms assumed in using numerical bisection to solve such problems: $g(\theta_2) - \hat{B} < 0 < g(\theta_1) - \hat{B}$. Progressive searches between $\theta_1$ and $\theta_2$ allow us to solve for the value of $\hat{\theta}$ that satisfies $g(\hat{\theta}) = \hat{B}$. See Judd (1998) for further discussion.

$$\theta_1 = \left[ \frac{\dfrac{\partial R}{\partial d} - \dfrac{\partial MCS}{\partial d}}{(P - d\hat{\beta})^{\hat{\alpha}b} \left( \dfrac{d_0}{m - R(\cdot)} \right)^{b-1}} \right]^{1/b} \quad [16]$$

Data from the hedonic study were used to develop the components that must be estimated to use this equation. Boyle, Poor, and Taylor [1999] measured water quality in terms of secchi disk readings in meters. Therefore, we used an approximate conversion factor (1.11) to express water quality in terms that are compatible with the other studies (i.e., as mg/l of DO).[19] In equation [16], $d$ was evaluated at the average DO with the water quality level converted from the hedonic study (4.6 mg/l). For the marginal rent expression, $\partial R/\partial d$, the annualized value of the marginal price for water quality (in terms of DO) from the Waterville sample in the study was used ($182).[20] In the denominator, the travel cost, $P$, was taken from the Englin et al. study and adjusted up to account for the higher average income (and thus higher opportunity cost of time) in Boyle, Poor, and Taylor's Waterville sample ($65 per trip).[21] The income net of rent, $(m - R)$, was estimated to be $67,426.[22] These adjusted measures of travel cost and net income, along with $\hat{\beta}$ and $\hat{\alpha}$, were then also applied in equations [14] and [15] to compute the value of $\partial MCS/\partial d$ (in the numerator of equation [16]) that is consistent with conditions in the the Boyle et al. study ($10.45).

Simplifying equation [13] results in the following expression for households' WTP for a non-marginal change in water quality.

$$\text{WTP} = m - R(d_0, \ldots) - \frac{[(\theta_1 d_0)^b - (\theta_1 d_1)^b + (P - h(d_0))^{-\alpha}(m - R(d_0, \ldots))^b]^{1/b}}{(P - h(d_1))^{-\alpha}}. \quad [17]$$

The Mitchell and Carson study described water quality to survey respondents in terms of a set of "use-supporting" categories—non-boatable, boatable, fishable, and swimmable. For our example, we use the study's WTP estimate for a water quality increment from non-boatable to fishable levels. Applying the RFF water quality ladder (Vaughan [1981]), these categories can be converted to comparable minimum levels of DO, such that $d_0 =$ 3.0 mg/l (non-boatable conditions) and $d_1 =$ 5.0 mg/l (fishable conditions).[23] Survey respondents were, on average, willing to pay $186 (1983 dollars) for this improvement described as an improvement at a national level to all fresh water bodies. We scaled this result down by a factor of 0.7 in our example to reflect WTP for a regional scale change in water quality.[24] The income net of rent, $(m - R)$, for the Mitchell and Carson sample was estimated to be $22,178. The travel cost, $P$, was adapted from the Englin et al. study. In this case, it was adjusted downward to account for the relatively lower average income in the Carson and Mitchell sample ($21 per trip). An important aspect of these adjustments is the adaptations made to the available information from different studies (i.e., in this case the travel cost) to make the variables needed for the equation correspond to values that are consistent with the conditions for the study providing that WTP estimate.

To solve for the final two parameters, we note that for every value of $b$ in equation [16], there is a unique solution for $\theta_1$ (using $\hat{\beta}$ and $\hat{\alpha}$ and and the information from the he-

[19] The conversion factor was estimated from available data in Smith and Desvousges [1986] linking dissolved oxygen, secchi disk and turbidity. We do not claim it is ideal or even the best that can be done. It is a necessary approximation estimated from a regression model. It is highlighted here to identify the need for conversion and call attention to the general need for consistent measures of water quality. These are essential to linking across results from different benefit measurement.

[20] This uses an annualization factor of 0.116, which adjusts for tax effects (Poterba 1992).

[21] This is accomplished by scaling travel cost by the relative income net of rent from the two studies.

[22] Average annual income in the Waterville sample was $77,388, and rent was calculated as the annualized value of the average property price ($85,880)

[23] This approach ignores the other features of water quality that affect the water body's ability to support the activity and implicitly assumes they change in the amounts required to support the activity change.

[24] In the Mitchell and Carson study, respondents were asked what portion of their stated WTP was for changes in local water quality. The median response was 70%.

donic study). Using this relationship, we can calibrate $b$ and $\theta_1$ by identifying the pair of values that also fit the definition of willingness to pay, as implied by equation [17]. The last two parameter values are $\theta_1 = 0.00018$ and $\hat{b} = 0.2697$.

## IV. USING THE CALIBRATED PREFERENCE FUNCTION

Table 3 illustrates how this function might be used for specific benefit transfers and how the results would differ from more simple unit-value transfers. The first two columns define alternative baseline and policy levels for water quality, measured in terms of DO levels. The first row considers a small change in dissolved oxygen (DO) inside the range spanned by the Mitchell and Carson question. The second row evaluates a larger change, outside the range in Mitchell and Carson. Columns three through five report values for the water quality changes that have been approximated using one of three unit value approaches. Columns six and seven report values that have been estimated using the calibrated WTP function. All estimates are reported on a per household basis.

Several aspects of these approximations should be noted before discussing how the unit-value transfer estimates compare with the estimates from the calibrated function. First, each measure begins its approximation from a different welfare concept. The travel cost measure of consumer surplus is the Marshallian measure of consumer surplus. Contingent valuation estimates Hicksian WTP and the hedonic property value is the marginal WTP (i.e., along what is assumed to be a constant utility locus). One would expect that the estimates derived using a simple CV unit-value approximation and the calibrated value using Mitchell and Carson's per household characteristics would be most directly comparable since they both reflect a Hicksian WTP measure. Second, and equally important, if the assumption underlying our preference specification is correct, then the travel cost and hedonic measures will provide overlapping coverage of some of the sources for water quality benefits, but not perfectly overlapping descriptions.

Our examples in Table 3 also demonstrate how simple income adjustments can affect unit-value transfers and calibrated transfer estimates. For the travel cost and the CV estimates we report per-household values that correspond to two different levels of income: (1) the average net income from the respective studies; and (2) the average net income from the hedonic study, which in both cases is significantly higher. All value estimates are rounded to the nearest dollar. The first column uses the Englin et al., travel cost estimate of Marshallian consumer surplus (and their average income, adjusted to 1995 dollars, and scaled to net out the annual rent). The unit value from this study is derived by taking the measured change in consumer surplus (\$36.34) and dividing it by the corresponding water quality change (2.0 to 5.0 mg/L). The resulting unit value is \$12.11 per unit DO. This unit value is then multiplied by the proposed policy increment to approximate the per household value of the water quality change. For the one and four unit DO increments, the per household values are \$12 and \$48 respectively. To obtain the estimates using the travel cost based approximations corresponding to the higher income level (column 4), the unit value is adjusted up by 2.54 (the ratio of the Boyle et al. net income to the Englin, Lambert, and Shaw [1997] net income). The seasonal benefits per household in this case are \$31 and \$123 respectively.

The same basic logic is applied to the CV estimates in columns 6 and 7. The unit value at the original income level is estimated to be \$102 per unit DO (based on an average WTP of \$203.11 for a DO change from 3.0 to 5.0 mg/l). The unit value for the higher income household is again estimated by scaling this value by the corresponding income ratio for the two studies (3.04). The annual per-household benefits are estimated by multiplying these unit values by the two policy increments. The benefit estimates from the hedonic study (column 5) are calculated using the marginal rental price as the unit value (\$182 per unit DO). No income adjustment is applied to this group since it already corresponds to the high-income category.

Columns 8 and 9 report the results of applying calibrated WTP function (i.e., equa-

TABLE 3

COMPARISON OF PER-HOUSEHOLD VALUES FOR WATER QUALITY CHANGES: CALIBRATED VERSUS SIMPLE APPROXIMATIONS AT TWO INCOME LEVELS (1995 $)

| Water Quality Change (mg/L of Dissolved Oxygen) | | Unit Value Transfer Approximations | | | | | Calibrated from WTP Function | |
|---|---|---|---|---|---|---|---|---|
| | | Travel Cost[a] | | Hedonic[b] | CV Estimate[c] | | | |
| Baseline ($d_0$) | Final ($d_1$) | $m - R$ = $26,523 | $m - R$ = $67,426 | $m - R$ = $67,426 | $m - R$ = $22,178 | $m - R$ = $67,426 | $m - R$ = $22,178 | $m - R$ = $67,426 |
| 4 | 5 | $12 | $31 | $182 | $102 | $309 | $96 | $188 |
| 3 | 7 | $48 | $123 | $728 | $408 | $1235 | $401 | $725 |

[a] The consumer surplus approximation is calculated by multiplying the per-trip per unit of dissolved oxygen CS estimate (from Englin et al. [1979]) by the size of the proposed policy change in dissolved oxygen and the average number of trips. Rounding accounts for small difference in row two ≈ 4 (row one).

[b] The hedonic approximation scales the marginal price by the size of the water quality change (i.e., $(\partial R/\partial d) \cdot \Delta d$, where $P$ is in annualized terms) using the secchi disk reacts corresponding to each quality change.

[c] The CV approximation is calculated by dividing the estimated WTP by the change in water quality for the original estimate and then multiplying by the size of the proposed policy change.

tion [17] with calibrated parameters). Per-household values for the two water quality changes are again estimated using two different income assumptions.[25] Using income levels from the CV study (column 8), the values from the calibrated function are similar but lower than the corresponding CV unit-value approximations. When evaluating water quality changes that differ from those in the CV study, the concavity of the WTP function (with respect to $d$) constrains the benefit estimate in a way that is consistent with the assumed preference structure. This constraint does not apply to the linear approximation used in columns (3)–(7). Similarly, when the calibrated WTP function includes income from the hedonic study and evaluates water quality changes in a range higher than those in the hedonic study (column 9), the values from the calibrated function are similar but lower than the corresponding hedonic unit-value approximations.

The most dramatic evidence of the importance of incorporating the income constraint arises in comparing our calibrated estimates using the Boyle, Poor, and Taylor (1999) income (column 9) with the corresponding CV-based estimates. Simple income adjustments to the CV-based estimates imply values over seventy percent larger than our calibrated estimates, which impose the income constraint. Also, it is interesting to note that if one were to naively add the hedonic and travel cost results, assuming that they capture separate and mutually exclusive values (even though they do in fact overlap), this would lead to overestimates of 13–17% relative to the calibrated values. These calculations are intended to be illustrative—indicating how the difference in the approaches for treatment of the water quality change and income can lead to marked differences in the transferred values. In the final analysis, there is no basis for saying any one is closer to the "true" value. However, with the measures derived from the calibrated function we know they satisfy some minimum conditions for consistency.

Overall, our example also draws attention to four issues in consistently using benefit information for transfers.

1. The task associated with developing benefit estimates to evaluate a new policy should be interpreted as an *identification problem*. That is, when transferring benefits we must judge whether there is sufficient information to develop a *theoretically consistent* measure of the benefits for the changes being considered.
2. Benefit estimates assembled from studies that used different methods will often yield results that have the same aspect of environmental quality represented with different technical measures. Consistent use of these benefit estimates requires that compatible indexes of environmental quality be developed. In short, these different technical measures of the environmental amenity must be reconciled. Differences in how a correspondence in measures is established may well be as important to errors as any distinctions in economic assumptions underlying the transfer process.[26]
3. To reconcile multiple, overlapping measures of people's incremental benefits from changes in non-market resources (such as the recreational and residential benefits examined in our example) the analyst must specify, through the preference structure, how each method's assumed margin for adjustment relates to the reasons for desiring the resource. This specification will yield a description of how the sources of benefits from each method are being "counted."
4. The observed economic tradeoffs that people make to obtain increases in non-market resources are constrained by their available incomes. Therefore, when transferring benefits, we must ensure that the measured WTP is affordable, that is, within people's dis-

[25] The different income assumptions require corresponding adjustments to the travel cost estimates, as was done in the calibration process.

[26] This conclusion is supported by the recent Desvousges, Johnson, and Banzhaf (1998) meta-analysis for environmental costing.

posable income. None of the existing approaches to benefit transfer meets a simple income test. It is particularly important to do so when considering large changes. Extrapolations using constant unit benefit estimates (or functions that describe how they change with demographic or environmental variables) cannot incorporate how available resources constrain effective tradeoffs a person can make. For small changes the effects can go unnoticed while for large ones they cannot.[27]

## V. ESTIMATION OF POTENTIAL EXTENSIONS OF THE PREFERENCE CALIBRATION LOGIC: METHOD OF MOMENTS

The possibilities for using the preference calibration logic do not stop with these simple numerical computations to recover one set of calibrated parameters estimates of a preference function. Preference calibration also offers a new strategy for using the benefit estimates in the existing literature as data to ''estimate'' the preference function used in benefit transfers. Instead of using meta-analysis to estimate reduced form response functions from the existing literature (see Smith and Huang [1995]), the logic of preference calibration implies that there may exist sufficient information to *identify* the parameters of preferences. When multiple sets of benefit estimates are available it is possible to specify a system of equations defining how each benefit measure relates to the common preference specification, as our examples do, and then to use each as defining a moment condition (see Smith, Pattanayak, and Van Houtven [2001]). In this context the basic logic would be implemented with multiple sets of estimates as ''data.'' The logic can be illustrated by returning to our general description of the calibration logic, beginning with the preference function given in equation [1].

Estimation of preference parameters based on a large set of estimates would take the types of equations illustrated in Table 1 and use them as moment conditions for estimating the parameters in [1].[28] Given the relevant independent variables for each study, these equations can be stacked: the common parameters provide cross-equation restriction and thus a basis for estimating the unobserved preference parameters. Adding errors to each condition and specifying a set of instruments allows the consistent use of multiple sets of benefit estimates.

Equally important, there is no reason to assume that the information consists exclusively of benefit measures or parameter estimates. We could combine some parameter estimates with a new sample. This route is one application of Imbens and Lancaster's [1994] proposal for combining micro and macro data to jointly estimate a structural model's parameters using a generalized method of moments method.[29] In our case the estimates of consumer surplus or marginal willingness to pay estimates from existing studies are defined in terms of the model's parameters and serve a role analogous to their ''macro data.'' A new study's results with individual data, assumed to arise from a common preference function, are comparable to their micro data. This logic is similar at a conceptual level to the logic of joint estimation but does not require that two types of responses be available for each individual.

[27] This issue is not limited to quantity changes. Harberger (1971) recognized its importance in evaluating the effects of price distortions. All his consumer surplus measures constrained total expenditures on all the goods affected by the price changes to remain constant.

[28] A moment is the expectation of a random variable, with the $r$th moment $u^r = E(y^r)$, where $y$ is the random variable and $r = 0, 1, 2, \ldots$. In the context of estimation, a method of moments estimator relies on being able to express the moments of a random variable in terms of the parameters of its probability distribution. The sample estimates of these moments are then used, along with the assumptions of invertibility of the function(s), to recover the parameter estimates.

Our comments here refer specifically to the generalized method of moments (GMM). This approach extends the basic logic of a method of moments estimator. GMM allows the use of sets of nonlinear functions of random variables and unknown parameters expressed as moment conditions. With GMM, there can be more moments than parameters. Estimation relies on minimizing a weighted distance function. See Ruud (2000), 536–57 for further discussion.

[29] See Smith (2000) for an example of this logic using two independent data samples to estimate the recreation losses due to oil spills.

## IV. DISCUSSION

Most of the problems with benefit transfer practices arise from the fact that the available literature in non-market valuation has not successfully estimated a complete willingness to pay function. Hedonic models usually offer point estimates of the marginal willingness to pay holding all else constant. Even the successful examples, where a second stage function is recovered (e.g., Boyle, Poor, and Taylor [1999] for water quality), usually do not include sufficient information to be used for benefit estimation in other policy applications.[30] Moreover, they do not describe how marginal willingness to pay changes with the prices of other goods or with the amounts of other amenities that are not at the specific sites studied but might be relevant to how those individuals' choices would change under new conditions. Thus, if alternative conditions are relevant to a transferred site, it would be important to incorporate them in the WTP function.

Our method can be considered as a simple approach for imposing some economic consistency on transfers using the information that is available. We argue it is possible to maintain some theoretical consistency with incomplete information by specifying a preference function and then calibrating the function's parameters to match the results defined by specific point estimates of benefits. We illustrate this logic with an example. We also argue that, when more information on benefit estimates is available, the same logic would call for using the relationships underlying calibration as "moment conditions" for the estimation of preference parameters.

Congressional mandates now call for benefit-cost analyses to evaluate the performance of regulatory programs (see U.S. Office of Management and Budget [2000]). If responses to these requirements are to avoid discrediting the practice of benefit-cost analysis, they must recognize the need for imposing internal consistency on measures of the gains (and losses) attributed to interrelated (from the consumer's perspective) but independently administered regulatory policies. Because the economic benefits of any exogenous change are unobservable, the onus of responsibility is on analysts to make their benefits estimates as plausible and theoretically consistent as possible. Calibrated preference functions provide a basis for consistent benefit measures *and* plausibility checks. That is, the models could be used to predict how recreation demand or housing expenditures changes after environmental quality improves (or declines). These predicted indirect measures of consumer responses could be evaluated for their plausibility in relation to past changes of these variables.[31] The resulting consistency with expected behavior would provide one basis for confirming that the policies "delivered" the estimated benefits. A calibrated benefit function, derived from a consistent description of budget constrained preferences, is a *first step* toward enhancing the economic consistency of transferred benefit measures.

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[30] This first point is simply a matter of reporting requirements. Professional journals do not allow space for complete reporting. Full documentation to assist subsequent policy transfers is a costly activity. To some extent policy analysts are "free riding" on research conducted for other objectives. It is therefore not surprising that the available documentation does not meet the first best needs for policy. A change in this situation will presumably require some support for these activities. It is probably too optimistic to expect it will take place because of the ease of using web sites to post backup material for published research. Moreover, it is also important to distinguish between making data available for replication from making models and results user friendly for transfers. The latter requirement is more difficult to encourage without incentives.

[31] While these evaluations do not assure that the realized benefits exactly match what was estimated, the observed activities (e.g., recreation or housing demands) have the expected correlation with the environmental quality. That is, even if the size of the estimates is not exact, the sign of the association is correct.

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