June 1979

APPROACHES TO MEASURING PUBLIC GOODS DEMANDS

A. Myrick Freeman III *

INTRODUCTION

Although some public finance textbooks still teach that public goods demands cannot be measured,[1] substantial progress has been made in developing and implementing techniques for measuring one form of public good--the benefits of improving environmental quality. This paper presents a brief review of the three major approaches to estimation of demands and benefits and a somewhat more detailed discussion of those techniques which are based market interactions between public and private goods. The analysis is limited to those public goods which are arguments in individual utility functions. Public goods which are inputs in production processes for marketed goods, for example, air quality in agricultural production, affect cost, supply, and factor demand functions and through them affect one or more of the following: output prices, factor prices, and profits (quasi-rents). The benefits of increases in public goods supply can be measured in a conceptually straightforward manner from observable market data. See Freeman (1979a) for an elaboration.

INDIVIDUAL DEMANDS FOR PUBLIC GOODS

The first step is to outline a basic model of individual preference and demand which incorporates a public good such as

Presented at AAEA meetings, Pullman, July 29- Aug. 1, 1979.

environmental quality as an argument in the utility function. This will establish the basis for describing various approaches. The analysis is limited to only one individual so that the problem of consistent aggregation to market demand curves can be ignored. Assume a utility function of the following form:

$$U = U(X,Q) \qquad (1)$$

where X is a vector of private goods ($X = x_1,\ldots,x_i,\ldots,x_n$) and Q is the level of environmental quality taken to be fixed to the individual. Maximizing utility subject to a budget constraint:

$$\sum_i p_i x_i = M$$

where M is money income, leads to a set of ordinary demand functions:

$$x_i = x_i(P,M,Q) \qquad (2)$$

Note that in general it is possible that environmental quality could be an argument in private goods demand functions.

The dual to the utility maximization problem can be stated as follows: minimize expenditures ($\sum_i p_i x_i$) subject to the constraint that utility as defined by (1) equal or exceed some stated level, say $U.^*$ The solution to this problem gives the expenditure function:

$$E(P,Q,U^*) = M \qquad (3)$$

The derivative of the expenditure function with respect to any price gives the Hicks-compensated demand function for that good, i.e.:

$$x_i{}^* = \partial E/\partial p_i = E_{p_i}(P,Q,U^*) \qquad (4)$$

The compensating variation and equivalent variation measures of the welfare changes associated with changes in market price can be easily interpreted in terms of equation (3). Similarly the derivative of (3) with respect to Q gives the Hicks-compensated inverse demand function or marginal willingness to pay for environmental quality, $w^*(Q)$:

$$w^* = -\partial E/\partial Q = E_y(P,Q,U^*) \qquad (5)$$

The benefit to the individual for a nonmarginal increase in Q is:

$$b=-\int_{Q1}^{Q_2} E_y(P,Q,U^*)dQ \qquad (6)$$

The main question addressed in this paper is under what circumstances and by what techniques can information on (5) or (6) can be obtained.

EMPIRICAL APPROACHES

One approach involves analyzing data from market transactions in goods and services related to various measures of environmental quality. Under certain circumstances, the demand for improvement in Q can be estimated from market data on the demand for goods and services which have substitute or complementary relationships with Q. Examples of these approaches include: the use of property value differentials; household expenditures on cleaning, maintenance and repair of materials damaged by pollutants; and travel costs incurred to participate in outdoor recreation.

The second approach is simply to ask individuals, through surveys and direct questioning, what value they place on a specified change in Q or how much Q they would "purchase" at a given stated price. One well-known problem with this approach is the incentives individuals may have to give biased answers for strategic reasons. In addition to these strategic biases, there is some evidence that certain structural characteristics of surveys have the potential for biasing responses. For example, in order to make the questions seem realistic, some surveys have stated that the vehicle for repayment will be an increase in the sales tax, or a surcharge on electric utility bills. If the respondents have some attitudes concerning the chosen means of repayment, this could introduce vehicle bias into responses. Also, in many surveys the questioner announces a value and then adjusts it upward or downward in fixed increments depending on the response. The starting point can also introduce a bias.

It appears to be possible, however, to design survey questions so as to eliminate the incentives for biased response. The general approach is to design the survey instrument so as to minimize the occurrence of any linkage between a subject's response and either an actual repayment or an actual outcome.[2] But devices to eliminate incentives for biased responses also have a second effect. They reduce the incentive to provide accurate responses. An accurate response is one which is consistent with the behavior which would be revealed if the good in question could actually be offered in a market. In the real world, an individual who takes an action inconsistent with his basic preferences, perhaps by mistake, incurs a cost or a loss of utility. In the purely hypothetical survey situation, there is no cost to being wrong, and therefore no incentive to undertake the mental effort to be accurate. The more hypothetical the situation posed to the individual, that is, the farther removed the situation is from his normal everyday experience, the less likely is the answer to be accurate. This is a problem which has not yet been seriously addressed in the literature on willingness to pay surveys.

Another problem with surveys has to do with perceptions and how to portray accurately the hypothetical situation to respondents. For example, if the purpose of the survey is to estimate the benefits of a specified water quality improvement, the questioner must find a way to describe the improved water quality accurately and in sufficient detail so that all respondents are reacting to similar perceptions of water quality improvement. Some of the best survey studies have combined photographs with descriptive textual material, e.g., Brookshire, Ives, and Schulze, and Randall, Ives, and Eastman. But there are limits to the ability of both words and pictures to convey effectively all of the aesthetic dimensions associated with Q.

In summary, at the theoretical level the problems of bias, accuracy, and perceptions must give one pause about the effectiveness of surveys in measuring willingness to pay. However at the practical level there is very little evidence concerning the seriousness or the magnitude of the errors introduced by these three problems. It would be very useful to have comparative studies of benefit estimates derived by alternative techniques. Very few of these have been done.[3] In the meantime, information derived from such surveys can be considered useful but not definitive.

A third approach is to place proposals which consist of alternative levels of Q and associated tax increases to referendum vote. Under certain circumstances the outcome of the voting process will be consistent with, and therefore reveal information about, the underlying demand curve for improved Q. The outcome of a referendum in any one jurisdiction only reveals whether the proposed level of AEQ and the associated tax burden were preferable to the status quo for a majority of voters. However, if the outcomes of elections or referenda in a large number of jurisdictions are observed simultaneously, it can be assumed that they approximate the median preferences in each jurisdiction. Then each jurisdiction can be taken as a sample unit, and the data on the quantity of the good or service, price or tax share, and socio-economic characteristics such as income, education, and occupation can be pooled and analyzed by multiple regression techniques to determine the relevant price and income elasticities of demand. Examples of this approach include Bergstrom and Goodman and Borcherding and Deacon.

Where all costs are financed through taxes in the voting jurisdiction and all benefits accrue to residents, voting can yield unbiased information on demand and on the optimum provision of Q. But where some of the benefits accrue outside the region, voting behavior does not capture all of the relevant demand for Q. And where some of the costs are shifted out of the jurisdiction, voters are not responding to the true price; thus voting reveals information about only a limited (and not the most relevant) portion of the demand function.

MARKET APPROACHES

In this section I use *a priori* assumptions to impose certain restrictions on the form of individual utility and demand functions. Different types of restrictions have different implications for the measurability of public goods demands from market data. The first assumed restriction leads to a situation in which it is impossible to estimate the demand for Q from market data.

A Hopeless Case. Suppose that the utility function is strongly separable with Q as the single argument in one of the subsets. In other words:

$$U = V[u^a(X_a) + u^b(X_b) + u^c(Q)]$$

where X_a and X_b are subsets of marketable goods. Strong separability means that the marginal rates of substitution between any pair of goods in X are independent of Q. Changes in Q have no effect on marginal rates of substitution of any of the marketable goods. Q can be excluded as an argument in all of the market demand functions. Although changes in Q affect utility, they leave no record of this impact in the data on market transactions.

Thus in principle it is not possible to estimate the demand for Q from observable market data on transactions in X when the utility function is strongly separable in Q.

Strong separability is a property of two of the most commonly used functional forms for utility functions--the Cobb-Douglas and the CES. This can be seen by writing them in their log transformations. Separability may be a characteristic of an important class of benefits. For example, those amenities of the urban environment which are not directly associated with private goods consumption may be separable. The option value associated with the preservation of unique natural environments is also likely to be separable.[4]

Weak Complementarity. For some forms of utility functions, the private goods demand functions do contain Q as arguments:

$$x_i = x_i(P,Q,M) \tag{8}$$

Suppose that this system of demand equations has been estimated econometrically and that the system satisfies the Slutsky Conditions for integrability. Is it then possible to integrate this system to solve for the underlying utility function and expenditure function? If the answer is yes, then it would be possible to compute public goods demand or willingness to pay functions from market data whenever private good demand functions had this form.

The answer is that in general it is not possible to solve completely for the utility and expenditure functions with the information given. Mathematically the result of the integration contains unknown terms which are themselves functions of Q and the constants of integration (Mäler, pp. 183-189). It is necessary to impose additional conditions on the problem in order to solve for the unknown terms and determine the constants of integration. The additional conditions involve what Mäler has called "Weak Complementarity."

Weak complementarity is defined by Mäler to occur if when the quantity demanded of a private good x_i is zero, the marginal utility or marginal demand price of Q is zero. The weak complementarity assumption would seem to apply to a number of useful situations. For example, the marginal value of water quality in a particular lake could be assumed to be zero for those people who did not use the lake for recreation. The marginal value of air quality over a particular residential site would be zero for those who did not live at that site.

Since direct application of the weak complementarity method as described here would require the econometric estimation of complete systems of demand equations, it would appear to be of relatively limited practical significance. Fortunately the weak complementarity conditions also permit the estimation of the demand price for Q without solving for the underlying utility and expenditure functions. This latter method requires only information on the demand for x_i, the weakly complementary private good. When Q increases the demand curve for x_i shifts out. Mäler (pp. 185-186) has shown that the benefit of the improved Q can be measured by the area between the old and new demand curves for x_i. In those cases where weak complementarity is not strictly true, i.e., when the willingness to pay for Q is positive even with zero x_i, then this area understates the true demand for Q.

If the analysis uses the Hicks-compensated demand curve for x_i, the area between the curves is an exact measure of the compensating variation measure of benefits. If an expression can be formulated for this area as a function of Q, the derivative of this function with respect to Q is the marginal demand price for Q. Typically what is known is an ordinary demand curve, not a Hicks-compensated demand curve. Willig has established conditions under which areas under ordinary demand curves can be taken to be close approximations of the precise compensating or equivalent variation measures. A straightforward extension of Willig's analysis shows that if the income elasticity of demand for x_i is constant over the range of variation, his conditions also apply to areas between ordinary demand curves. Thus for practical purposes, the technique described here can be applied to market data.[5] The primary empirical requirement for utilizing this technique is that we be able to obtain econometric estimates of the demand function for the private good as a function of Q as well as prices and income. This requires observations of the market for x_i under different quantities of Q. If Q has never changed, there is no possibility of identifying the partial relationship between Q and the demand for x_i.

<u>Perfect Substitutes</u>. Mäler (pp. 116-118) has shown that the partial derivative of the expenditure function with respect to Q is equal to the price of the private good times the marginal rate of

substitution between it and Q. This would be a useful practical result if it were possible to derive simple expressions for the marginal rate of substitution.

Suppose the utility function is weakly separable and is of the following form:[6]

$$U = V\{u^a(X_a), [c x_i^{-\rho} + (1 - c)Q^{-\rho}]^{-1/\rho}\} \tag{9}$$

(x_i is not in X_a). Given the separability assumption, the marginal rate of substitution between x_i and Q is independent of the quantities in X_a. Then the marginal willingness to pay is

$$w^* = -P_{x_i}\left(\frac{c}{1 - c}\right)\left(\frac{Q}{x_i}\right)^{1/\sigma}$$

where σ is ρ-1.

In general, to use this formulation, we need to know both the elasticity of substitution, σ, and "c". There is one special case where the expression reduces to a usable term. If x_i and Q are perfect substitutes in consumption, the elasticity of substitution between them is infinite, and the expression for the marginal demand price of Q reduces to $P_{x_i} r$, where r is the equivalence or substitution ratio between x_i and Q.[7] If perfect substitutability can be assumed, r (or c) should be computable from known or observable technical consumption data.

The perfect substitutability assumption lies behind the "defensive expenditures" technique for estimating benefits of pollution control. Defensive expenditures (or what Zeckhauser and Fisher call averting behaviors) are expenditures made to prevent or counteract the adverse effects of pollution. If defensive expenditures are a perfect substitute for reductions on the level of pollution effects experienced, then an individual can effectively purchase the optimal amount of Q through defensive outlays. In practice, defensive outlays which would be perfect substitutes for Q would be rare. There is no such thing as a perfect defense. There are some disutilities associated with pollution that cannot be prevented by further spending. This is equivalent to saying that σ is less than infinite. Hence, changes in defensive outlays are likely to give underestimates of the true benefits of the changes in Q. Nevertheless, recognizing this limitation, analysis of changes in defensive outlays related to pollution could substantially narrow our range of ignorance about benefits.

Hedonic Prices. The techniques described so far have been developed for the case where the level of public good provision or environmental quality is fixed and the same for all individuals. Although this represents one polar extreme, it is not descriptive of all possible cases involving public goods or environmental quality. Individuals can choose the level of consumption of local public goods through their choice of a jurisdiction to reside in. Also there are important cases where individuals have some freedom to choose their effective consumption of environmental quality through their selection of a private goods consumption bundle. Where these choices are possible, information on public good demand is embedded in the prices and consumption levels for private goods. For example, if air quality varies across space in an urban area, individuals may choose their exposure to air pollution through their residential location decisions. Residential housing prices may include premiums and discounts for locations in clean or dirty areas. It may be possible to estimate the demand for clean air from the price differentials revealed in private markets. The demand function for Q is estimated through a two-step procedure in which first the implicit price of Q is estimated by the application of the hedonic price technique, and then the implicit prices are regressed against observed quantities to estimate the demand function itself.

The hedonic technique is a method for estimating the implicit prices of the characteristics which differentiate closely related products in a product class.[8] Let X represent a product or commodity class. Any unit of X can be completely described by a vector of its characteristics. Continuing with the housing example, let c_i represent the specific characteristics of a structure and its lot, and Y_j represent neighborhood characteristics such as quality of schools, and Q represent air quality. Then for any unit of X, say x_1,

$$P_{x_1} = P_x(c_{11},\ldots,c_{1i},\ldots,c_{1n},Y_{11},\ldots Y_{1j},\ldots Y_{1m},Q_1) \qquad (10)$$

The function P_x is the hedonic or implicit price function for X. If P_x can be estimated from observations of the prices and characteristics of different models, the price of any model can be calculated from knowledge of its characteristics.

The implicit price of a characteristic can be found by differentiating the implicit price function with respect to that characteristic. This gives the increase in expenditure on X that is required to obtain a model with one more unit of that characteristic, ceteris paribus. If (10) is linear in the characteristics, then the implicit prices are constants for individuals. But if (10) is non-linear, then the implicit price of an additional unit of a characteristic depends on the quantity of the characteristic being purchased, and perhaps on the levels of other characteristics, too. Linearity will occur only if consumers can "arbitrage" activities by untying and repackaging bundles of attributes (Rosen, pp. 37-38).

Under some circumstances it may be possible to use the information contained in the implicit price function to identify the demand relationship for a characteristic--even if the characteristic is a public good such as environmental quality. First assume that each individual purchases only one unit of X, or if he purchases more than one, they are identical models. Otherwise the individual facing a nonlinear hedonic price function might be observed to act upon two different implicit prices for the same characteristic. Also assume that the utility function is separable in X and its characteristics. This makes the marginal rate of substitution between any pair of characteristics independent of the consumption of any good other than X. Without separability, the demand for a characteristic would in fact be a function of the consumption levels of other goods; and the estimation of the second stage demand function would require additional price and quantity data beyond that derived from the hedonic price function.

For the i^{th} individual, the quantity, Q_i, is known by observation and its implicit price P_{Qi} is known from the implicit price function. Can individuals' marginal willingness to pay functions be identified from these observations? The answer depends on the circumstances of the case. If the implicit price function is linear in Q, then it is not possible to identify a demand curve for Q. The price observation is the same for all individuals. However the marginal implicit price can be interpreted as the marginal willingness to pay or marginal benefit for small changes in Q for each individual. If equation (10) is nonlinear, the ability to identify the demand curve depends on the specification of the underlying model. For further discussion, see Freeman (1979a) and Rosen.

If inverse demand functions for individuals can be identified, benefits of changes in Q can be calculated by taking areas under the demand curves bounded by the old and new levels of Q. Since these are not income-compensated demand curves, the areas are approximations of the true compensating variation measure.

SUMMARY

In this paper I have reviewed approaches to estimating public goods demands which use surveys or bidding games, observations of voting behavior, and observations of market behavior. The market approaches have the virtue of providing measures in a monetary metric and of being based on actual behavior rather than responses to hypothetical questions.

One of the more promising techniques is based on the concept of weak complementarity. Benefits are measured in terms of shifts in the demand curve for the private complementary good. The approach is applicable to estimating recreation benefits due to the water quality changes.

Where the public good is a perfect substitute for a private good, benefit estimation is straightforward if the substitution ratio and the price of the private good are known. Defensive expenditures and measures of additional costs (for example, for household cleaning, or medical care and drugs in the case of health) are examples of estimates that are based upon approximations of the perfect substitute assumption. The less perfect the defense, the more inaccurate is the estimate based upon the perfect substitute assumption.

Another promising case is where the public good varies across space, as in air pollution or noise, or is a characteristic embodied in some private good. Then individuals can choose different Q's by varying residential locations or by choosing different private good models. The hedonic price approach can be used to measure the implicit price of Q; and under some circumstances the demand curve for Q can be identified.

Footnotes

* Department of Economics, Bowdoin College. I am very grateful to V. Kerry Smith for a number of helpful discussions of various aspects of the paper.

[1]See for example Due and Friedlaender, who say: "...since individuals know that if the public good is provided at all they cannot be excluded from its benefits regardless of their monetary contributions towards its cost of production, there is no mechanism to make them reveal their actual preferences or marginal rate of substitution between public goods and private goods...The very essence of the public goods problem is that there is no way these preferences can be determined." (Due and Friedlaender, pp. 48 and 53. Emphasis added.)

[2]For a general discussion, see Freeman (1979a, Chapter 5). Examples of this approach include Hammack and Brown, Knetsch and Davis, Randall, Ives, and Eastman, Bohm, and Brookshire, Ives, and Schulze.

[3]For example, see Knetsch and Davis, who found good correspondence between estimates of recreation benefits based on a survey and on the Clawson-Knetsch travel cost technique. And Brookshire, d'Arge, and Schulze found that their bidding game and property value studies produced comparable estimates of the benefits of improved air quality in the Los Angeles area.

[4]For discussion of the option value concept, see Cicchetti and Freeman.

[5]See Stevens for an application of the weak complementarity approach to the estimation of the benefits due to water quality improvement.

[6]The following discussion is based on Mäler (pp. 178-183).

[7]$r = c/(1 - c)$. For example, if $c = .75$, then $r = 3$. This means that one unit of Y is a perfect substitute for three units of x_i.

[8]The hedonic price technique was developed by Griliches and others initially for the purpose of estimating the value of quality change in consumer goods. Rosen has used the hedonic price concept to analyze the supply and demand of the characteristics which differentiate products in competitive markets. For discussion of the application of the concept to measuring the demand for environmental quality characteristics, see Anderson and Crocker, Bishop and Cicchetti, and Freeman (1979a) and Freeman (1979b).

References

Anderson, Robert J. and Thomas D. Crocker. "Air Pollution and Property Values: A Reply." Review of Economics and Statistics. 54 (1972): 470-473.

Bergstrom, Theodore C. and Robert P. Goodman. "Private Demands for Public Goods." American Economic Review. 63 (1973): 280-296.

Bishop, John and Charles J. Cicchetti. "Some Institutional and Conceptual Thoughts on the Measurement of Indirect and Intangible Benefits and Cost," in Henry Peskin and Eugene Seskin, eds., Cost Benefit Analysis and Water Pollution Policy. Washton, D.C.: The Urban Institute, 1975.

Bohm, Peter. "Estimating Demand for Public Goods: An Experiment." European Economic Review. 3 (1972): 111-130.

Borcherding, Thomas E. and Robert T. Deacon. "The Demand for Services of Nonfederal Governments." American Economic Review. 62 (1972): 891-901.

Brookshire, David S., Ralph C. d'Arge, and William D. Schulze. Methods Development for Assessing Tradeoffs in Environmental Management, Vol. II, Experiments in Valuing Non-Market Goods: A Case Study of Alternative Benefit Measures of Air Pollution Control in the South Coast Air Basin of Southern California. Washington: Environmental Protection Agency, 1979.

Brookshire, David S., Berry C. Ives, and William D. Schulze. "The Valuation of Aesthetic Preferences," Journal of Environmental Economics and Management. 3 (1976): 325-346.

Cicchetti, Charles J. and A. Myrick Freeman III. "Option Demand and Consumer's Surplus: Further Comment." Quarterly Journal of Economics. 85 (1971): 528-539.

Due, John F. and Anne F. Friedlaender. Government Finance, Economics of the Public Sector, 5th Ed. Homewood, Illinois: Irwin, 1973.

Freeman, A. Myrick III. The Benefits of Environmental Improvement. Baltimore: Johns Hopkins University Press, 1979a.

Freeman, A. Myrick III. "Hedonic Prices, Property Values, and Measuring Environmental Benefits: A Survey of the Issues." Scandinavian Journal of Economics in press.

Griliches, Zvi., ed. Price Indexes and Quality Change. Cambridge: Harvard University Press, 1971.

Hammack, Judd and Gardner M. Brown, Jr. Waterfowl and Wetlands: Toward Bioeconomic Analysis. Baltimore: Johns Hopkins University Press for Resources for the Future, 1974.

Knetsch, Jack and Robert K. Davis. "Comparisons of Methods for Recreation Evaluation" in Allen V. Kneese and Stephen C. Smith, eds., Water Research. Baltimore: John Hopkins University Press for Resources for the Futures, 1966.

Mäler, Karl-Göran. Environmental Economics: A Theoretical Inquiry. Baltimore: Johns Hopkins University Press, 1974.

Randall, Alan, Berry Ives, and Clyde Eastman. "Bidding Games for Evaluation of Aesthetic Environmental Improvement." Journal of Environmental Economics and Management 1 (1974): 101-204.

Rosen, Sherwin. "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." Journal of Political Economy. 82 (1974): 34-55.

Stevens, Joe D.. "Recreation Benefits from Water Pollution Control." Water Resources Research. 2 (1966): 167-182.

Willig, Robert D.. "Consumers' Surplus Without Apology." American Economic Review. 66 (1976): 589-597.

Zeckhauser, Richard and Anthony Fisher. "Averting Behavior and External Diseconomies." Mimeo, 1976.