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ON THE MEASUREMENT OF ENVIRONMENTAL IMPROVEMENTS BY PUBLIC AVERTING BEHAVIOR

HOANJAE PARK*

This paper attempts to make theoretical and practical framework for measuring welfare changes in environmental improvements by public averting behavior, based on Park's (1996) model. Welfare measures from externalities with public averting behavior are not well established in the existing literature. By this reason, many researchers have confusion about welfare measures for environmental improvement by public averting behavior. In an article, Cropper and Oates (1992) try to integrate all welfare measures in the environmental literature. Although it is correct overall, it is not integrated in a satisfactory way, especially for the public averting behavior. Thus this paper attempts, theoretically and practically, to integrate welfare measures for public goods under the subject of public averting behavior model. In our model, types of averting behaviors would depend upon alleviation technology. Assuming a simple linear technology, this paper examines valuation of environmental improvements by the public averting behavior. It is hoped that its extension is useful and applied in public and environmental economics.

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I. INTRODUCTION

The problem of externalities and the associated market failure had long been a part of microeconomic theory. The economists, however, had little impact on

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* Department of Economics, Catholic University of Taegu-Hyosung, 330 Hayang, Kyungsan, Kyungpook 712-702, Republic of Korea; fax: 053-850-3402; voice: 053-850-3415; email: parkhj @cuth.cataegu.ac.kr. This paper has benefited from the comments of professors D.E. Holthausen and R.B. Palmquist at North Carolina State University. So I wish to thank them for ideas and comments on this paper. But the usual caveat applies.

the legislation for the control of pollution and resource conservation. Now it seems an evolution time of economic incentives for environmental protection. Public and environmental economists have paid attention to measure the benefits and costs of pollution control and its associated program.

Some studies analyze the benefits of environmental improvements when households take private averting actions to alleviate pollution's effects [see Watson and Jaksch (1982), Gerking and Stanley (1986), Smith and Desvousges (1986), Bartik (1988), and Dickie and Gerking (1992)]. This literature often derives inferences about willingness-to-pay for improved health, safety, or environmental quality from individuals' choices of protective action. In this literature of competitive framework, averting behavior is a purely private activity: the benefits accrue solely to the particular victim who takes averting behavior. The examples are enormous: clean or repaint exterior of house; install air purifiers or air conditioner in response to air pollution etc.

There, however, can be instances where averting behavior has public good characteristics.[1] This article analyzes the benefits of environmental improvements by public averting behavior using a new testing approach in the averting behavior literature: weak-complementarity and weak-neutrality. The problems in measuring the demand for a public good are well known. However, the analysis of implicit markets for public-good characteristics within averting behavior approach are not well established.

The development of methods to measure the benefits of environmental goods and services has been of central concern to date. The methodologies developed so far can be classified into two categories. One is indirect market methods, which attempt to infer from actual choices, while the other is direct questioning methods, which ask people to make tradeoffs between environmental and other goods in a survey context. This article focuses on the former methods.

The present paper will extend Park's (1996) model with the assumption that averting behavior is purely public. Some of the results are reached by others, say that benefits of marginal quality improvement can be measured in a weakly complementary private market to the quality. This article, however, extends it to the weakly neutral private market in order to capture nonuse value or existence value of the quality. It also proposes a new way to separate those markets. A main contribution of this article is thus to provide a new testing and evaluating approach to analyze the benefits of environmental improvements when public averting actions are taken to alleviate pollution's effects.

In the section II, this paper will set up a fairly general model, following Park's model. In the section III we shall examine the problem by diagrammatic exposition. In the section IV, we will analyze the benefits of environmental improvements under the assumption that averting behavior is public. Section V will illustrate an empirical application from market demands. In the section VI,

[1] See, for example, Park (1996).

we will propose a new testing approach to which markets are included in valuing public goods and which conditions are more accurate description of preferences, weak complementarity, weak neutrality, or neither. In the section VII, we shall summarize this article followed by brief concluding remarks.

II. THE MODEL OF PUBLIC AVERTING BEHAVIOR

The standard analysis begins with Park's model in which the activity of producing certain goods generates an external diseconomy on individuals (Mr. A and B) in the system.[2] The economy characterizes pollution (S) as a public bad resulting from waste emissions associated with the production of private goods (X). To reduce the level of pollution, a public averting behavior (A) is employed, which is a function of tax expenditures (t). The tax is assumed to be used solely to fund public averting actions and contribute directly to the provision of the public quality. The basic model can be described as:[3]

$$U_A = U(X_A,\ Q) \tag{1}$$

$$Q = Q(A,\ S) \tag{2}$$

$$A = A(t_A,\ t_B) \tag{3}$$

Equations (1) is the utility function for Mr. A and utility is positively related to the individual consumption of a vector of goods, X, and negatively related to the individual's exposure to emission or positively related to the quality Q. S is the resulting pollution from emission and Q is the quality purchased by mitigating pollution through the function Q(·). The amount of A indicates the public averting behavior to avert public bad (S). Thus equation (2) may be called an anti-damage (purchased quality) function or alleviation function in which environmental quality is improved by alleviating the effects of pollution through the use of public averting action (A).

In this model, we can solve to maximize the utility of Mr. A subject to (2)-(3) as constraints along with a further constraint on budget availability:

$$p_x X_A = M_A - t_A \tag{4}$$

where p_x is a price vector of X. Further we can classify various averting behaviors depending on the averting behavior technology [A(·)].[4] The fact that averting activity is possible means that the quantity of pollution (S) entering into

[2] The individual B is interpreted as all other persons than Mr. A in a competitive equilibrium.

[3] Throughout the paper, subscripts of letter denote the individuals in question; superscripts of naught and one denote a pre-change variable and a post-change variable in question, respectively.

[4] See Park (1996) for details. In Park (1996), Z(·) corresponds to Q(·) here.

the utility can be made smaller than the quantity that would have entered if the victims had remained completely passive, denoted by S. Simplifying the model, we assume that the public averting behavior technology has the following form:

$$A = A(t_A, t_B) = (t_A + t_B)/P \tag{5}$$

assuming that public agency faces the price, P, which is assumed to be one.

Meanwhile, the implication of the anti-damage production (alleviation technology) relationship [Q(·)] between averting activity A and the level of pollution (S) depends upon functional forms of the production technology of pollution. In the above, the anti-damage production technology has taken a fairly general form

$$Q = Q(A, S) \tag{6}$$

If S is assumed as the quantity of emission when the victims remain completely passive and Z is the level of S after removing some amount of emissions through the averting activity A, we might rewrite as:[5]

$$Z = S - K(A, S)A \tag{7}$$

where $K(A, S)$ might be interpreted as a variable unit cost in real terms depending upon S. The $K(\cdot)$ may be called the congestion function as in the Public Finance Literature. However, in this context it would rather be called a unit alleviation function because S will be removed effectively as $K(\cdot)$ becomes higher. The damage production technology, Z, may be classified into several types according to its unit alleviation function: those whose alleviation function depends upon (a) the quantity of emissions; or (b) the scale of alleviation activity; or, most common, (c) both. To simplify the analysis, it is assumed that

$$K(A, S)A = K(S)A \tag{8}$$

where K is a constant.[6]

A point here is that we may use interchangeably "anti-damage by averting activities" and "environmental quality" since we can express the above as

$$Q = -Z = -[S - KA] \tag{9}$$

[5] Heuristically, the cost of alleviation activity could be written as follows: $A = E(S-Z)$ where E is real expenditure of alleviation activity. Noting that Z depends upon S, A and inverting the above expression, we obtain: $Z = S - E^{-1}(A)$. Then letting E^{-1} to K and considering K dependent on S and A, we obtain the final form same as the above.

[6] This type is the simplest linear case but the more general case is that $Z = S - K(S, A)$ where $K(\cdot)$ is nonlinear.

where Q indicates the environmental quality purchased by the averting actions (A). As averting activities are increasing, the quality of environment Q will increase proportionately. In fact, Q is an effectively removed public bad $S(-Z)$ so that it is implicitly assumed one to one correspondence between Q and S. Q and A are assumed to have one to one correspondence in this as well [$K=1$]. Thus the function Q is explicitly defined as

$$Q=A-S=(t_A+t_B)/P-S. \tag{10}$$

Since the initial level of S is assumed given, dropping S in $Q(\cdot)$ would not change the analytic results. Thus S is dropped in the later analysis.

III. DIAGRAMMATIC EXPOSITION OF THE PROBLEM

Consider our model in Section II. In our model, people care only about the total level of averting activities, where utility depends purely on the public good Q. Because Q is a pure public good characteristic, it is available to all individuals in the economy regardless of their own private contribution. Under the model, individuals are indifferent to the source of the public good. Given this initial set of preference and the alleviation technology, how will the public averting actions be valued by the individuals?

Reformulating it, the individual A maximizes its utility function subject to the budget constraint:

$$\max U_A(X_A,\ Q(A,\ S)) \qquad \text{s.t. } p_x X_A = M_A - t_A \tag{11}$$

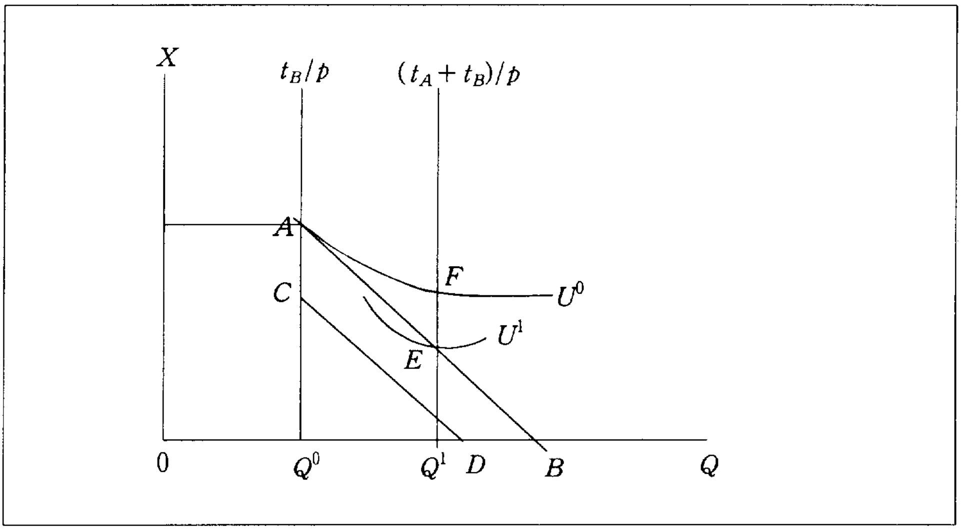
Solving this yields Marshallian demand functions as functions of price, income, tax and the provision of public goods:

$$X_A^* = X_A^*(p_x,\ M_A,\ Q,\ t_A) \tag{12}$$

With the help of Figure 1, the problem can be depicted. The private good X is shown on the vertical axis while the public good Q is shown on the horizontal axis. Without tax contribution, the individual may achieve a solution at point A.[7] With tax contribution, the individual has had t_A taken from his income to pay for the public good, Q. The transfer of t_A to the public agency shifts the budget constraint to CD. But public purchase of quality shifts the constraint out to AB. As a result, the level of tax financed quality purchase will become Q^1 and the individual will maximize utility at the corner marked by point E. The

[7] We do not rule a possible interior solution out and it does not change our analytic results.

[Figure 1] Tax Financed Quality Purchase



individual is now at the lower level of utility, U^1, because he is forced to consume Q^1 at the point E. To compensate the individual so that he regains the original level of utility requires the monetary value of the difference of utility, $U^1 - U^0$. Thus the value of the public program is equal to the tax minus the monetary value of the difference of utility which is the distance, EF. It provides a reference for the discussion.

The difference of utility, $U^1 - U^0$, can be formalized as follows. Substitution of the Marshallian demand functions (X_A) into utility function gives the indirect utility function, which is defined as

$$\begin{aligned} V(p_x, M_A - t_A, Q) &= max\{U_A(X_A, Q)|p_x X_A = M_A - t_A\} \\ &= U[X_A^*(p_x, M_A, Q, t_A), Q] \end{aligned} \tag{13}$$

This indirect utility function can be used to determine the value of a change in the non-market good, Q.[8] Let $Q^1 > Q^0$ by exogenous changes in Q and t where Q^i denotes Q at the situation $i(i=0, 1)$. Then the compensating variation (call it as CV_q) of a change in Q is defined as[9]

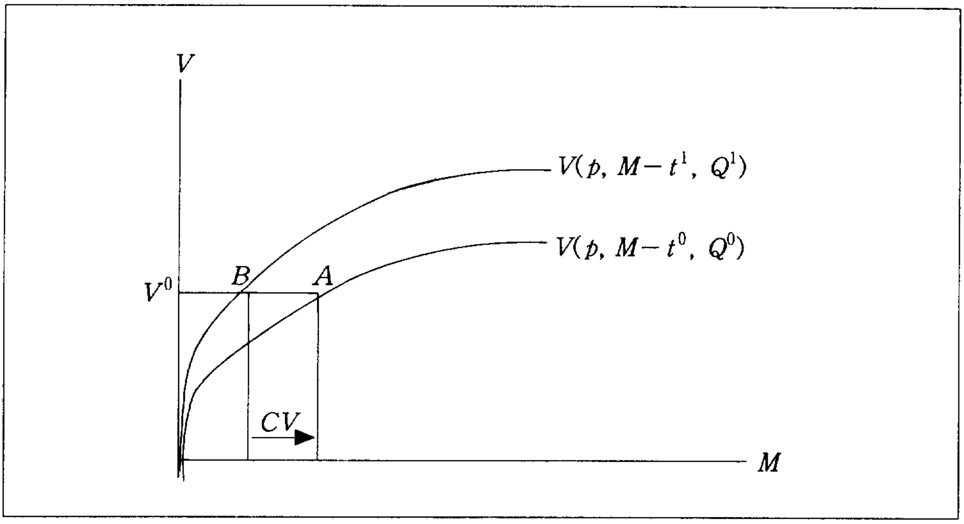
$$U^0 = V(p_x, M - t^0, Q^0) = V(p_x, M - t^1 + CV_q, Q^1) \tag{14}$$

where CV_q is the maximum amount of income the individual is willing to give

[8] It is, in fact, equivalent to the distance EF in figure 1.

[9] If we assume that both Mr.A and Mr.B have the same preference, i.e., Mr.A is a representative consumer, then we can safely drop the subscript A.

[Figure 2] Compensating Variation in Expenditure-Indirect Utility Space



up to obtain the change in Q. It provides the theoretical basis for valuing the public averting behaviors.

It can be illustrated in Figure 2. The vertical axis shows the level of indirect utility and the horizontal one indicates the amount of expenditure. In this figure, the level of tax collected from individuals is exogenous to the individual and by tax contributions, the total utility function shifts out to $V(p, M-t^1, Q^1)$. The utility constant payment for the publicly financed control program can be measured as income change AB in the figure, which is equivalent to CV_q.

Totally differentiating $V(\cdot)$, we obtain

$$dV^* = \frac{\partial V}{\partial M} dM + \frac{\partial V}{\partial Q} dQ + \frac{\partial V}{\partial M} dt \tag{15}$$

Solving for the change in income required to keep utility constant, we obtain

$$dM = -\frac{\partial V/\partial Q}{\partial V/\partial M} dQ - dt \tag{16}$$

This states that the marginal willingness to pay (MWTP) is simply the value of utility due to the change in the public good (Q) minus the value of the tax contributions since $\partial V/\partial Q$ is the marginal utility of Q and $-(\partial V/\partial Q)/(\partial V/\partial M) = MRS_{QM}$. Integrating eq. (16) over the range of the change in Q yields the willingness to pay function (WTP):

$$WTP = -\int_{M(Q^0)}^{M(Q^1)} dM = -\int_{Q^0}^{Q^1} MRS_{QM} dQ + \int_{t_0}^{t^1} dt \tag{17}$$

which is equivalent to a measure of CV_q without tax. As for this CV_q without tax, willingness to pay is the maximum amount of money the individuals would give up in order to enjoy a natural quality change. In policy implementation, if we subsidize the amount of CV_q for individuals, we may achieve Pareto-efficient equilibrium.[10]

IV. ECONOMETRIC VALUATION APPROACH OF PUBLIC AVERTING BEHAVIOR

Traditional averting behavior approaches rely on the fact that privately purchased inputs can be used to mitigate the effects of pollution. Smith and Desvousges (1986) study water pollution avoided by purchasing bottled water and Dickie and Gerking (1992) research pollutants in outdoor air filtered by running an air-conditioner. Thus these approaches show that the value of averting behavior (A) is measured by individuals' defensive expenditures for a small change in pollution (S) $[Q=Q(A,S)]$. The problem here is that the value of public averting behaviors is not the arithmetic sum of the values of private averting behaviors, but it should measure the value of pollution change, i.e., environmental quality improvements by public averting actions. Focusing solely on private expenditures ignores the value of the externalities received by others. As an example of trees in urban parks, they affect the quality of visitors' recreational experience, as well as the experience of others.

Since the averting behaviors are public goods in this paper, it is difficult to value them for the following reasons. First, the willingness to pay for public goods cannot be directly observed by the analyst. Second, the public goods are

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[10] The comparative statics for WTP with respect to quality is of interest to interpret welfare estimates associated with quality parameters. From (17), WTP can be written as

$$WTP=E(p_x,\ Q,\ V(p_x,\ Q^1,\ M))-M+(t^1-t^0)$$

where M is a constant of the initial expenditure and $M=E(q_x,\ Q,\ U^0)$. The change in the expenditure function from a change in the quality level (Q) is thus

$$\frac{\partial WTP}{\partial Q}=MRS_{QM}=\frac{\partial E(p_x,\ Q,\ U)}{\partial Q}=-p_Q^*(p_x,\ Q,\ U)$$

where $p_Q^*(\cdot\ ,\ U)$ is the inverse Hicksian demand for quality. This equation is similar to Equation (10) in Hanemann (1991). Hanemann calls it the fundamental differential equation, underlying Randall and Stoll's analysis. Substituting the indirect utility gives

$$\frac{\partial WTP}{\partial Q^1}=\frac{\partial E(p_x,\ Q,\ V(p_x,\ Q^1,\ M))}{\partial Q^1}=\frac{\partial M}{\partial V}\ \frac{\partial V}{\partial Q^1}=\left(\frac{\frac{\partial M}{\partial V}}{\frac{\partial M}{\partial V^1}}\right)\left(\frac{\frac{\partial V}{\partial Q^1}}{\frac{\partial V^1}{\partial M}}\right)$$
$$=-\left(\frac{\partial M}{\partial V}\Big/\frac{\partial M}{\partial V^1}\right)p_Q(p_x,\ Q^1,\ M)$$

where $p_Q(\cdot\ ,\ M)$ is the virtual price of quality and $V^1=V(p_x,\ Q^1,\ M)$. If quality is a normal good, the denominator will be greater than the numerator in the bracket since the marginal cost of utility is greater with higher V. It shows the relationship between the inverse Hicksian demand for quality and the virtual price of quality.

also non-market commodities so that no price can be observed. The analyst's ability to define the nonmarket commodities to be valued is determined by the valuation method employed. The methods used in the literature are indirect methods that rely on observable choices together with a maintained model of the motivations for those, and direct methods that use survey techniques to ask people how they would value hypothetical changes in the good of interest.[11] An enormous literature of both methods has been developed over the two decades or so. The examples of recent works are Bockstael and McConnell (1991), Cameron (1992), Larson (1992, 1993), Freeman III (1993), Hanemann (1995), Kwak and Jun (1995), Lee and Kwak (1996), Frykblom (1997).

The approaches below assume that we could turn to a secondary market that is related in a specific way to the quality characteristic rather than the hypothetical market for the quality itself. In some cases the quality of interest is attached to private goods. For example cleaner water (Q) is attached to a purchased good, e.g., visits to a lake (X). The conditions for welfare measurement in this case depend on the existence of an appropriately related secondary market.

A. THE WEAKLY COMPLEMENTARITY APPROACH

Following Hanemann (1991), we develop an approach which can be measured with market data. In order to do this, we now interpret the preference for the individual A in our model as follows:

$$U_A = f[U_1(X_{1A}, Q), U_2(X_{2A})] \tag{18}$$

where some function $f(\cdot)$ is increasing in its arguments and it implies that there are other goods (X_{2A}) weakly separable from X_{1A} and Q so that X_{1A} is not essential. In this preference, our model in section II has focused only on U_1 since U_2 is not of interest and even inclusion of it does not change our previous results. Suppose Q is a good which is weakly complementary to X_{1A} in the sense that if the price of good X_{1A} is so high that the good is not consumed, then its quality by averting activity does not matter.[12] Since X_1 is

[11] For the direct methods, Samuelson (1958) offers examples of ways to deal with allocation decisions involving public goods. He proposes that analysts interrogate people for their tastes with respect to public goods as to give each respondent the feeling that his answer can be a true one without costing him anything extra. This view seems to support the contingent valuation method (CVM). However, there have been hot debates on the reliability on CVM-based valuation. See Kahneman and Knetsch (1992) and V. Kerry Smith (1992) for discussion of these debates.

[12] [illegible]

weakly complementary with Q and $u = U^0$, we have[13]

$$\lim_{p_1 \to \infty} \frac{\partial V(p_1, Q, M)}{\partial Q} = 0, \tag{19}$$

or
$$\lim_{p_1 \to \infty} \frac{\partial E(p_1, Q, u)}{\partial Q} = 0, \tag{20}$$

where p_1 is the price of good X_1.[14] As assumed above, nonessentialness implies:

$$\lim_{p_1 \to \infty} E(p_1, Q, u) < \infty, \tag{21}$$

where $E(\cdot)$ indicates the conditional expenditure function.

Let the price p_1^c be a choke price at the level of Q as p_1 goes to infinity, which is defined by[15]

$$p_1^c = \min\{p_1 | X_1(p_1, Q, u) = 0\}. \tag{22}$$

Noting that by definition $E(p^c, Q, u) = p_1 X_1(p^c, Q, u) + p_2 X_2(p^c, Q, u)$, weak complementarity means

$$p_1 \frac{\partial X_1(p^c, Q, u)}{\partial Q} + p_2 \frac{\partial X_2(p^c, Q, u)}{\partial Q} = 0 \tag{23}$$

where $p^c = (p_1^c, p_2^c)$.

Using these assumptions, it is possible to have a money measure of averting action related to quality changes, which can be estimated solely from the demand for X_1. The change in the consumer's welfare, when p_1 is increased from p_1^0 to infinity, can be written as:

$$\begin{aligned} -CV_P &= E(p_1^0, Q^0, U^0) - E(\infty, Q^0, U^0) \\ &= -\int_{p_1^0}^{\infty} X_1(p_1, Q^0, U^0)\,dp_1 \\ &= -\int_{p_1^0}^{p_1^c} X_1(p_1, Q^0, U^0)\,dp_1 \end{aligned} \tag{24}$$

This measure gives the area to the left of the compensated demand curve for X_A between its intersection with the price axis and the price p_1^0.

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[13] Subscript A is dropped by the same reason as in footnote 8 and taxes in expenditure are subsumed.

[14] Note that we do set p_2 (for the price of a sort of Hicksian composite good 2) to one.

[15] Simply stated, it is the price intersecting the price axis when Q is at some level.

Now we change Q from Q^0 to Q^1. In this case, differentiating (24) with respect to Q and then integrating the result between Q^0 and Q^1, we obtain:

$$\begin{aligned}-CV_q &= -\int_{p_1^0}^{\infty}\int_{Q^0}^{Q^1}\frac{\partial X_1}{\partial Q}(p_1,\ Q,\ U^0)dQdp_1 \\ &= -\int_{p_1^0}^{\infty}[X_1(p_1,\ Q^1,\ U^0)-X_1(p_1,\ Q^0,\ U^0)]dp_1.\end{aligned} \tag{25}$$

This is the compensated money measure of a change in the public averting action, or a change in the quality of a private good X_1. In terms of conditional expenditure functions, we have (25) as:

$$-CV_q = E(p_1^0,\ Q^0,\ U^0)-E(p_1^0,\ Q^1,\ U^0). \tag{26}$$

If the change in public good provision is an increase, then the difference is positive and is referred as willingness to pay for the change.

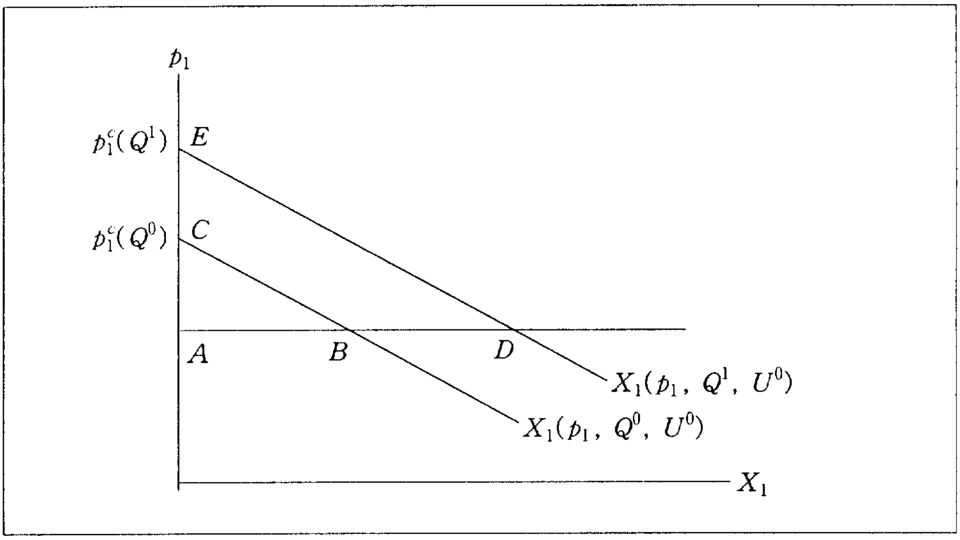
B. THE WEAK NEUTRALITY APPROACH

Weak complementarity in section A assumes implicitly that nonuse value is zero, so that the total value of an environmental quality change is the change in use value. Because of this, weak complementarity approach has defended itself only for zero nonuse value. It can be clearly viewed if eq. (26) is written, in three steps by changes in arguments, as:

$$\begin{aligned}-CV_q &= E(p_1,\ Q^0,\ U^0)-E(p_1,\ Q^1,\ U^0) \\ &= [E(p_1^c,\ Q^1,\ U^0)-E(p_1^0,\ Q^{1\cdot}\ U^0)] \\ &\quad +[E(p_1^0,\ Q^0,\ U^0)-E(p_1^c,\ Q^0,\ U^0)] \\ &\quad +[E(p_1^c,\ Q^0,\ U^0)-E(p_1^c,\ Q^1,\ U^0)]\end{aligned} \tag{27}$$

In the second line of eq. (27), the three brackets can be considered, in sequence, as the three step procedure to evaluate welfare change in Q. Each bracket shows the steps of how to evaluate CV_q. It can be illustrated with the help of Figure 3. The first bracket shows the amount that the individual A would lose by the area ADE when the price of X_1 rises from p_1^0 to $p_1^c(Q^1)$ (the choke price at Q^1). The second bracket shows the amount that he would gain by the area ABC when the price of X_1 returns from $p_1^c(Q^0)$ (the choke price at Q^0) to p_1^0. The third bracket shows nonuse value, which is the change in expenditure function when consumption of the private goods is held at zero. In this approach, he does not lose anything at the choke price p_1^c when Q rises from Q^0 to Q^1 because utility does not change if $X_1=0$ by weak complementarity.[16] In other words, non-use value is zero, which is generally not true without

[Figure 3] The Welfare Effect of Change in Q Attached in a Private Good X_t



the assumption of weak complementarity. The welfare effect of change in Q will then be obtained by the sum of money amounts in three steps, which is given by the area of [ADE-ABC], i.e., CBDE. Consequently it provides the way to value changes in Q by the derived demand function for goods (X_1 here).

However, individuals would value having particular resources that they would not use but exist. That is individuals can realize increased utility without using resources in any tangible way. Suppose, for example, Hicksian composite good X_2 is a good that is neutral to Q in the sense that expenditure will be invariant to the change in the price of X_1 induced by the change in Q. X_2 is called as the Hicks-neutral good. If it occurs when some quality level needs threshold level and price changes to the choke price, it is called as weak-neutrality. Thus, weak neutrality is different from Hicks-neutrality in that Hicks-neutrality assumes that all of the value of a change in environmental quality is nonuse value while weak neutrality does not set nonuse value to the total value of a change in Q.[17]

For some good X_i and a price vector p^c, weak neutrality can be defined by

$$\frac{\partial X_i(p^c, Q, u)}{\partial Q} = 0 \tag{28}$$

If weak neutral commodity exists in the preference, then the total value of a

[16] Without weak complementarity condition, utility would change (decrease) so that another welfare loss comes in for the second step.

[17] Another possible description is that if good X_2 is neutral to quality for all prices, it is the Hicksian neutrality while the weak neutrality holds for some prices.

change in Q can be measured and decomposed into use and nonuse values without weak complementary preference. In order to separate nonuse value from use value, the composite commodity (X_2 in this case) must be neutral at p^c. If this were not true, the Hicksian demand for the composite commodity would shift with quality (prices held constant) and would generate a use value. Thus if, at a given price vector (p^c), all of the change in value with a quality is nonuse value, it allows the weak neutrality condition to be applied to the composite commodity, i.e.,

$$\frac{\partial X_2(p^c, Q, u)}{\partial Q} = 0. \tag{29}$$

For some lakes or dams with unusual features (good quality) or few good substitutes, weak complementarity may not be suitable for an accurate description of preferences because nonuse value is not likely to be zero. Suppose that X_1 is travel to the lake and $X_2 = M - p_1 X_1$ is expenditure on all other things. The use value can be written

$$\begin{aligned} \text{Use Value} &= \int_{p_1^0}^{p_1^c} \frac{\partial E}{\partial p_1}(p_1, Q^1, U^0)dp_1 - \int_{p_1^0}^{p_1^c} \frac{\partial E}{\partial p_1}(p_1, Q^0, U^0)dp_1 \\ &= \int_{p_1^0}^{p_1^c} X_1(p_1, Q^1, U^0)dp_1 - \int_{p_1^0}^{p_1^c} X_1(p_1, Q^0, U^0)dp_1 \end{aligned} \tag{30}$$

where $p_1^c(0, Q, u)$ is the choke price adjusted to the quality changes which is the Hicksian inverse demand evaluated at $X = 0$, and

$$\begin{aligned} \frac{\partial X_1(p_1^c(Q), Q, U^0)}{\partial Q} &= \frac{\partial X_1(p_1^c(Q), Q, U^0)}{\partial p_1} \frac{\partial p_1^c(Q)}{\partial Q} \\ &\quad + \frac{\partial X_1(p_1^c(Q), Q, U^0)}{\partial Q} \end{aligned} \tag{31}$$

implicitly defines how the choke price adjusts to changes in quality. If neutrality of the composite good at the choke price applies, nonuse value is given by the change in the expenditure function with Q given the choke price. Thus nonuse value is

$$\begin{aligned} \text{Nonuse Value} &= \int_{Q^0}^{Q^1} \frac{\partial E}{\partial Q}(p_1^c, Q, U^0)dQ \\ &= \int_{Q^0}^{Q^1} \frac{-p_1^c \dfrac{\partial X_1}{\partial Q}(p_1^c, Q, M)}{\left[1 - p_1^c \dfrac{\partial X_1}{\partial M}(p_1^c, Q, M)\right]} dQ \end{aligned} \tag{32}$$

Eq. (32) can be derived by noting the following identities,

$$X_1(p, Q, u) = X_1(p, Q, E(p, Q, u)) \tag{33}$$
$$X_2(p, Q, u) = X_2(p, Q, E(p, Q, u)), \tag{34}$$

differentiating (35) with respect to Q:

$$X_2(p, Q, E(p, Q, u)) = M - p_1 X_1(p, Q, E(p, Q, u)), \tag{35}$$

and applying the weak neutrality condition:

$$\frac{\partial X_2(p^c, Q, u)}{\partial Q} = 0. \tag{36}$$

The equation (32) proves possible to identify the marginal valuation of the quality change in terms of the coefficients in the demand function of X_1.

V. AN ILLUSTRATION OF ECONOMETRIC VALUATION

In the previous section, we have analyzed the consumer's welfare mathematically. This section will illustrate an empirical application concerning measurement of nonuse value and use value from market demands under weak complementarity and weak neutrality.

As an illustration, the AIDS specification for demand will be used, which is more flexible and easier to estimate than any other specification. For the analysis as simple as possible, the price vector of all other goods except X_1 is set to one. Following Hauseman (1981), consider then the following simple expenditure function with a quality variable:

$$\log E(p, Q, u) = (1-u)\log a(p) + u \log b(p) \tag{37}$$

where $\log a(p) = \alpha_0 + (\alpha_1 + \delta \log Q)\log p_1 + 1/2\, r_{11} \log p_1 \log p_1$

$\log b(p) = \log a(p) + \beta_0 p_1^{\beta_1} Q^{\delta}$

Interpretation of $a(p)$ and $b(p)$ is from Deaton and Muellbauer (1980) that if utility is scaled such that $0 \le u \le 1$, then $a(p)$ gives the value by which p must be divided to reach subsistence ($u=0$) and $b(p)$ is the value by which p must be divided to achieve bliss ($u=1$). In other words, as utility increases from 0 to 1, expenditure increases from $a(p)$ to $b(p)$ with change in budget shares. Hence a total expenditure of $a(p)$ can be thought of as poverty expenditure, while $b(p)$ is affluence expenditure. The role of quality variable in this interpretation is to shift increasingly or decreasingly the poverty (subsistence) expenditure and affluence (bliss) expenditure, respectively.

Given the above assumptions, eq. (37) implies that

$$\log E(p,\ Q,\ u) = \alpha_0 + \alpha_1 \log p_1 + 1/2\, r_{11}(\log p_1)^2 + \delta \log p_1 \log Q + u\beta_0 p_1^{\beta_1} Q^{\delta} \tag{38}$$

The AIDS demand function can be derived from the fact that logarithmic differentiation of the log expenditure function with respect to its price gives the budget share:

$$w_1 = \alpha_1 + r_{11} \log p_1 + \delta \log Q + u\beta_0 \beta_1 p_1^{\beta_1} Q^{\delta} \tag{39}$$

By inverting expenditure function, we derive the indirect utility function and substitute the result into the above, which gives the final form of the AIDS demand function:

$$w_1 = \alpha_1 + r_{11} \log p_1 + \delta \log Q + \beta_1 \log (M/P) \tag{40}$$

where P denotes a price index equal to $\exp[a(p)]$. Changes in relative prices work through the term r_{11} with (M/P) held constant and changes in real expenditure operate through the coefficient β_1.

The compensating variation for changes in quality can be implicitly defined by

$$\log[E(p,\ Q^1,\ u) - CV(\Delta Q)] = \log[E(p,\ Q^0,\ u)] \tag{41}$$

It follows that

$$\log(1 + CV/M) = \log E(Q^1) - \log E(Q^0) \tag{42}$$

Using the expenditure function and manipulating algebraically, we obtain

$$\begin{aligned} \log(1 + CV/M) &= u\beta_0 p_1^{\beta_1}(Q_1^{\delta} - Q_0^{\delta}) + \delta \log p_1 \log(Q^1/Q^0) \\ &= \left[\frac{Q_1^{\delta}}{Q_0^{\delta}} - 1\right]\left[-\alpha_0 - \alpha_1 \log p_1 - \frac{1}{2} r_{11}(\log p_1)^2 - \delta \log p_1 \log Q^0 + \log M\right] \\ &\quad + \delta \log p_1 \log(Q^1/Q^0) \end{aligned} \tag{43}$$

If all the parameters are estimated, CV can be calculated. The nonuse value in this case is that

$$\begin{aligned}\text{Nonuse Value} &= \int_{Q^0}^{Q^1} \frac{\partial E}{\partial Q}(p_1^c,\ Q,\ U^0)dQ \\ &= \int_{Q^0}^{Q^1} \frac{-\dfrac{\partial X_1}{\partial Q}(P_1^c,\ Q,\ M)}{\left[(1/p_1^c) - \dfrac{\partial X_1}{\partial M}(p_1^c,\ Q,\ M)\right]} dQ \\ &= \int_{Q^0}^{Q^1} \frac{\delta M}{\beta Q} dQ\end{aligned} \tag{44}$$

as p_1 goes to infinity. Since $(1/p_1^c)$ goes to zero as p_1 goes to infinity, the marginal willingness to pay for the quality change is $\delta M/\beta Q$, which is varying with change in quality. The total value of the quality change is then the sum of use value (CV) and nonuse value.

Some simulation results are tabulated in table 1 for several values of α, δ, and β for the case in which $p_1 = 1.5$, $r = -0.6$, $M = 100$, $q^0 = 2$, and $q^1 = 2.5$.[18] In these simulations, the coefficient δ is important to determine the magnitude of the compensating variation and nonuse value. As the size of the coefficient δ is increasing, both the compensating variation (CV) and nonuse value (NV) are increasing. On the other hand, the coefficient β strongly affects the nonuse value but affects the compensating variation in a weekly positive way. Thus, the simulations confirm that when the quality elasticity is large, which implies the larger coefficient δ, then both CV and NV are increasing. Furthermore, when the income elasticity is large, which implies the greater coefficient β, then it has week effects on the CV positively but strong effects on the NV. For example, when the income elasticity is rising from 1.2 to 1.5 holding quality elasticity constant, the change in the nonuse value is more than a twofold magnitude but the compensating variation is increasing by a small amount. The relatively moderate increase in the income elasticity (from 1.5 to 1.6) and decrease in the quality elasticity (from 0.21 to 0.11) are combined with lower values of compensating variation and nonuse value.

[Table 1] Simulations of the CV and NV for the Almost Ideal Demand System

α	δ	β	Income Elasticity	Quality Elasticity	$\frac{CV}{M}$	$\frac{NV}{M}$
0.15	0.06	0.12	1.2	0.12	0.069421	0.045
0.15	0.11	0.12	1.2	0.21	0.131263	0.082
−0.45	0.11	0.25	1.5	0.21	0.138123	0.039
−0.75	0.07	0.35	1.6	0.11	0.087722	0.018
0.40	−0.01	−0.02	0.7	−0.17	−0.010865	0.045
0.45	−0.03	−0.03	0.4	−0.63	−0.032082	0.090

[18] The parameter values in these simulations are chosen to satisfy the budget constraint, which ensure that the budget share is positive but less than one.

As we know, the income elasticity is greater than one as long as the coefficient of the income variable is positive in the almost ideal demand system. Thus the simulation for the case of the income elasticity less than one is done in the fifth row. In addition, we assume that the coefficient of the quality variable is negative, which implies that a rise in quality results in a slight decline in predicted demand for good x. It does not necessarily follow that because an exogenous quality indicator is a good, it will have positive Marshallian or Hicksian quality slopes. In this assumption, the increase in quality is a "good," but it shifts the Marshallian or Hicksian demands for x inward, though less realistic. The fifth and sixth rows in the simulations show that the compensating variation falls as the quality elasticity is negative and the smaller income elasticity generates higher values of the nonusers.

VI. TESTING FOR WEAK-COMPLEMENTS AND NEUTRALS

In order to be confident of obtaining the correct total valuation of the quality change, all weak complements must be included in the demand system. The neutrality assumption is also required because any change in the expenditure function as quality changes can be interpreted as nonuse value when consumption of all complements is held at zero. In this section, the question of which private goods are included in the demand system is answered.

This paper proposes mixed demand systems in testing for weak complementarity and neutrality to quality variable. The rationale for it is that the quality variable is usually treated as exogenous to individuals while quantity variables of all private goods are considered as endogenous. The Slutsky relationship in a mixed demand system is developed using the concept of virtual price of the quality purchased by the public program. If p_i denotes the nominal price of good X_i and M is total expenditure on $X=[X_1 X_2 X_3]$ and Q, then $v_i = p_i/M$ is the corresponding normalized price. The mixed demand system is derived from the constrained optimization problem:

$$Max_x[\,U(X,\ Q) + \max_{v_Q}[-V(v) | v'X + v_Q Q = 1]] \tag{45}$$

where $v=[v_1\, v_2\, v_3]$, and $v_Q = P_Q/M$, and $V(\cdot)$ denotes the indirect utility function. The solution to the problem gives Marshallian mixed demands:

$$\begin{aligned} &X(v,\ Q,\ 1) \\ &v_Q(v,\ Q,\ 1) \end{aligned} \tag{46}$$

At the optimum, $U[X(v,\ Q,\ 1)] = V(v,\ Q,\ 1)$. The homogeneity condition implies

$$X(v,\ Q,\ 1)=X(p,\ Q,\ M) \qquad (47)$$
$$v_Q(v,\ Q,\ 1)=p_Q(p,\ Q,\ M)$$

where $p=[p_1\, p_2\, p_3]$.

The compensated demand can be characterized in terms of the restricted expenditure function $E(p,\ Q,\ u)$ defined as $Min_X\{p'X|U(X,\ Q)=u\}$. The partial derivative with respect to Q gives the compensated virtual price of Q. In the mixed demand case the total cost of achieving utility level u when $(p,\ Q)$ are given is

$$E^*(p,\ Q,\ u)\equiv E(p,\ Q,\ u)+P_Q(p,\ Q,\ u)Q \qquad (48)$$

where $p_Q=-\frac{\partial E}{\partial Q}$. The mixed expenditure function $E^*(\cdot)$ allows one to relate compensated and Marshallian mixed demand functions via the identities:

$$X(p,\ Q,\ u)=X(p,\ Q,\ E^*) \qquad (49)$$
$$p_Q(p,\ Q,\ u)=p_Q(p,\ Q,\ E^*)$$

These identities can be used to derive useful Slutsky relationships. Defining the Slutsky submatrices $s_{ij}=\frac{\partial[X(p,\ Q,\ u),\ p_Q]}{\partial[p,\ Q]}$, it then follows that

$$\begin{bmatrix} \frac{\partial X}{\partial p} & \frac{\partial X}{\partial Q} \\ \frac{\partial p_Q}{\partial p} & \frac{\partial p_Q}{\partial Q} \end{bmatrix} = \begin{bmatrix} s_{11}-s_{12}s_{22}^{-1}s_{21} & s_{12}s_{22}^{-1} \\ -s_{22}^{-1}s_{21} & s_{22}^{-1} \end{bmatrix} \qquad (50)$$

This gives the properties of the compensated mixed demand functions X and p_Q: $\partial X/\partial p$ and $\partial p_Q/\partial Q$ are symmetric, negative semi-definite while the symmetry relationship $\partial X/\partial Q=-[\partial p_Q/\partial p]'$ holds. In this matrix, good X_i is a substitute (respectively, complement) for good Q if $\partial X_i/\partial Q<0$ (respectively, >0) or $\partial p_Q/\partial p_i>0$ (respectively, <0).[19]

Given the above discussion and properties, it will suffice to identify the set of Hick-nonneutral goods in the empirical mixed demand system. Then the demand system would include the goods whose Hicksian demands shift directly with quality. If X_1 is weakly complementary to Q, then the goods X_2 and X_3 are aggregated into the composite commodity, which is weakly neutral to Q at the choke price of X_1. If the composite commodity is not neutral at the choke price, then its Hicksian demand would shift with quality and generate a use value.

As an illustration, consider the almost ideal demand system in section V

[19] See Madden (1991).

again

$$w_i = \alpha_i + \sum_{j=1}^{3} r_{ij} \log p_j + \delta_i \log Q + \beta_i \log (M/P). \tag{51}$$

Differentiation of (51) with respect to $\log(Q)$ shows the property of the coefficient of quality variable:

$$\delta_i = \frac{\partial w_i}{\partial \log Q} = w_i \frac{\partial \log X_i}{\partial \log Q} = w_i \varepsilon_{iQ} \tag{52}$$

where ε_{iQ} denotes the elasticity of demand for X_i with respect to quality Q. Thus the parameter δ_i includes the information about the Slutsky relationship to show complements, substitutes, and neutrals to Q. If $\delta_i > 0$, then it implies that demand for good i is increasing as quality level is increasing by public averting actions. The discussion below eq. (50) confirms that good X_i and quality Q are complements. Similarly if $\delta_i < 0$, then it implies that demand for good i is decreasing as quality level is increasing. It shows that good X_i and quality Q are substitutes. If $\delta_i = 0$, then it implies that demand for good i is neutral to the change in quality level, showing that good X_i and quality Q are Hicksian neutrals.

In this illustration, suppose that X_1 and X_2 are Hicksian-nonneutral commodities with $\delta_i > 0$ and X_3 are the composite commodity. Then eq. (51) will be the form of the estimation. Using the estimated parameters, we may be able to compute choke prices under the weak complementarity assumption.[20] In order to test weak neutrality, the same empirical demand system is used but the restriction that

$$\frac{\partial X_3(p^c, Q, u)}{\partial Q} = 0, \tag{53}$$

is imposed, which is equivalent to the following equation by the Slutsky relationship[21]

[20] The way to derive choke prices can be sketched as follows. First, the Hicksian demand function is derived by differentiating expenditure function. Thus it will be a function of p, Q, α, β, r, δ, β_0, and u, where all variables and parameters are vectors except β_0, u, and Q. Second, inverting the Hicksian demand function, the u can be expressed as a function of p, Q, α, β, r, δ, β_0, and the Hicksian demand X. Third, setting demand for X identically equal to zero, the price vector p will become a function of Q, α, β, r, δ, β_0, and u. Then the expression for u is substituted back into the expression for the price vector. It yields the choke prices (p^c) as a function of X, Q, α, β, r, δ, β_0, and the initial price vector p. Thus if all parameters are estimated, and the initial demands and prices are known, the choke prices can be obtained.

[Table 2] Simulations of Testing for Weak-Neutrality at Choke Prices in the Almost Ideal Demand System

$\alpha_1 = \alpha_2$	$\beta_1 = \beta_2$	δ_1	p_1^c	δ_2
0.15	0.12	0.06	3.455	0.70
0.47	0.15	0.11	6.910	0

$$\frac{\partial E(p^c, Q, u)}{\partial Q} = -\frac{\partial X_3(p^c, Q, M)/\partial Q}{\partial X_3(p^c, Q, M)/\partial M}. \tag{54}$$

It has expressed the change in the expenditure function with respect to quality given the choke prices (marginal willingness to pay for nonusers) in terms of observables, prices and the slopes of Marshallian demand functions. It implies that all prices p_i's should be constrained to be equal to choke prices and with this constraint the testing hypothesis is $\delta_3 = 0$(or $\delta_1 + \delta_2 = 0$), which amounts to no change in the expenditure function with respect to quality given the choke prices. If it is rejected, the weak neutrality condition is effective and vice versa. If this hypothesis is not rejected, then weak complementarity would be an accurate description of preferences.

A simple simulation result for the two good case is tabulated in table 2 for two values of α, δ, and β for the case in which $p_1 = 1.5$, $p_2 = 1$, $\gamma_1 = \gamma_2 = -0.6$, $M = 100$, $q = 2$. In these simulations, the coefficient δ_2 is important to determine the weak complementarity and weak neutrality conditions. For the first simulation, the weak-neutrality condition may be more accurate description of preferences since δ_2 is not zero while the second describes preferences more accurately by the weak-complementarity condition since $\delta_2 = 0$.

VII. CONCLUDING REMARKS

This paper attempts to integrate welfare measures for public averting behavior into the averting behavior model proposed by Cropper and Oates (1992). In our model, public averting behavior is described as tax financed purchasing quality. This property is characterized in the alleviation technology. Assuming a simple linear technology, this paper has examined valuation of environmental improvements by the public averting behavior. The marginal willingness to pay can be derived from the representative consumer's maximization and is simply

[21] By the adding-up, the equation is equivalent to the following:

$$\frac{\sum_{i=1}^{2} p_i^c \frac{\partial X_i}{\partial Q}(p_i^c, Q, M)}{\left[-\sum_{i=1}^{2} p_i^c \frac{\partial X_i}{\partial M}(p_i^c, Q, M)\right]}$$

the value of utility due to the change in quality minnus the value of the tax contributions.

In the traditional averting behavior model, the monetary value of averting behavior is measured by individuals' defensive expenditures. The value of public averting behavior, however, is not the arithmetic sum of the values of private averting behaviors. The weak complementarity approach can value quality improvements by public averting behaviors. It is, however, valid only if the total value of quality change is the change in use value. On the other hand, the weak neutrality approach can capture the nonuse value missing in the weak complementarity approach. Thus combination of the weak complementarity and weak neutrality approach can complete the total value of the change in tax-financed purchasing quality. An illustration of the mixed approach confirms that our approach is useful in empirical studies.

In the mixed approach, the most critical problem is that all weak complementary and neutral goods should be included in the empirical demand systems. To answer this question, this paper proposes a mixed demand system to test for weak complements and weak neutrals to quality. An illustration using the almost ideal demand system proves to be useful in empirical studies. It is one of the contributions to the existing averting behavior literature. It is also hoped that its methodology is applied in various areas of public and environmental economics.

Although this paper may provide useful insight into valuing public goods, it suggests at least two areas for further research. First, the importance of the technology of averting behavior (i.e., alleviation technology) suggests a need for an empirical examination of the relationship between the provision of public averting behavior and the severity of emission. Second, this paper did not cover the case where there are interactions among public goods provided by the public agency, leaving those topics for the future research.

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