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A note on how to undertake a cost-benefit analysis in monetary and environmental units

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Abstract

In this note we discuss two alternative ways of undertaking a social cost-benefit analysis. One approach is the conventional one where benefits and costs are expressed in monetary units. The other approach uses an environmental asset as the payment vehicle. The properties of the two approaches are discussed and the measurement problems are stressed.

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1 Introduction

Recently it has become quite popular to calculate compensation for the loss of some environmental asset. The technique often referred to as Habitat Equivalency Analysis (HEA) essentially calculates the amount, hectares, for

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example, that must be created to replace an equivalent level of ecological services that was lost due to an accident. The approach focuses on scaling replacement costs on a service-to-service basis. A similar technique, Resource Equivalency Analysis (REA), scales replacement costs on a resource-to-resource basis. Jones and Pease (1997) attributes the trend towards non-monetary compensation methods partly to the perceived problems of obtaining credible estimates of damages in monetary terms. A relatively early paper in the economics literature may also have been influential. Unsworth and Bishop (1994) suggested to use what they call "environmental annuities" as a shortcut to value wetlands, when monetary valuation methods are unavailable (for cost or other resource reasons). They based their method on the idea that "..the public can be compensated for the past losses in environmental services through the provision of additional services of the same type in the future" (p.35).

Non-monetary compensation methods have been extensively used in the U.S. under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 42 U.S.C. 9601 et seq.) and the Oil Pollution Act of 1990 (OPA, 33 U.S.C. 2701 et seq.). The legislative approach to damage assessment is different in the EU, yet recent changes imply a more frequent use of non-monetary compensation methods. Directive 2004/35/EC on Environmental Liability with regard to the prevention and remedying of environmental damage (OJ 2004 L 143/56, 30.4.2004) became effective in April 2004. The Directive stipulates that the public is compensated for the initial damage and the losses during the time the environment takes to recover back to baseline (interim losses). Annex II to the Directive sets out a framework that supports Member States in choosing the most appropriate remediation measures. Ozdemiroglu et al. (2009) summarizes the EU-funded REMEDE-project, which was designed to further develop the methods in Annex II of the Directive[1].

Economists, such as Flores and Thacher (2002), have pointed out a number of problems with non-monetary compensation. See also Dunford et al. (2004) and Zafonte and Hampton (2007). In this note we develop the economic analysis further from the standpoint of cost-benefit analysis. Typically a cost-benefit analysis is undertaken in monetary units. This is one of the two approaches employed in this note. The other approach uses an environmental resource as the "payment vehicle". We focus on the case where a costly project adds to environmental quality and individuals give up some-

[1]The project produced a toolkit, or Handbook, to be used in future applications. Some of the issues we discuss here in a formalized model are also touched upon in Ozdemiroglu et al. (2009)

thing of another environmental resource in order to remain at their initial or pre-project utility levels. The analysis can easily be adapted so that individuals pay the cost for developing a substitute for the loss of another and possible more or less identical asset as in HEA or REA. We briefly discuss the measurement problems one faces in basing the evaluation on monetary units and resource units, respectively. The approaches are illustrated by simple numerical illustrations[2].

2 Model

Consider a simple social welfare function in a two-individual society[3]:

$$W = W[V_1(y_1, E, E^o), V_2(y_2, E, E^o)] \tag{1}$$

where $V_i(.)$ is the indirect utility function of individual i, y_i is income of individual i, E denotes environmental quality of a "good" which is affected by the project to be considered, E^o is another environmental resource, and prices of all goods and services are suppressed.

Next, a project affecting incomes and environmental quality is considered:

$$\begin{aligned}\Delta W = W[V_1(y_1 - c_1, E + \Delta E, E^o), V_2(y_2 - c_2, E + \Delta E, E^o)] - \\ W[V_1(y_1, E, E^o), V_2(y_2, E, E^o)]\end{aligned} \tag{2}$$

where the project under consideration is associated with costs $c_i \geq 0$ and strictly positive environmental consequences[4] $\Delta E > 0$.

The individual willingness to pay (WTP)for this project is defined as follows:

$$V_i(y_i - c_i - CV_i, E + \Delta E, E^o) = V_i(y_i, E, E^o) \tag{3}$$

where CV_i is the WTP of individual i ($i = 1, 2$). The WTP might be negative.

However, it is also possible to define a WTP in terms of environmental quality:

$$V_i(y_i - c_i, E + \Delta E, E^o - CV_i^{E^o}) = V_i(y_i, E, E_i^o) \tag{4}$$

where $CV_i^{E^o}$ expresses how much environmental quality of the other environmental good the individual is willing to give up in exchange for the considered

[2]The paper draws on Johansson (1998).

[3]We assume for simplicity that utility functions are well-behaved and fully measurable; see, for example, Boadway and Bruce (1984) or (Myles 1995) for detailed discussion of these concepts.

[4]In a HEA the project replaces a substitute that has been damaged and should therefore be appropriately scaled.

project. As is the case with the monetary WTP, $CV_i^{E^o}$ might be negative if the project's costs are deemed too high relative to the project's benefits.

Now we are ready to define the project's impact on social welfare using our monetary WTP measures:

$$\begin{aligned} \Delta W = W[V_1(y_1 - c_1, E + \Delta E, E^o)), V_2(y_2 - c_2, E + \Delta E, E^o] \\ -W[V_1(y_1 - c_1 - CV_1, E + \Delta E, E^o), V_2(y_2 - c_2 - CV_2, E + \Delta E, E^o)] \\ = \sum_i W_i \cdot V_{y_i} \cdot CV_i \end{aligned} \tag{5}$$

where W_i denotes the marginal welfare weight is attributed to individual i, and V_{y_i} denotes his or her marginal utility of income, both evaluated at some intermediate income $y_{im} \in [y_i, y_i - c_i - CV_i]$.

Similarly, we might evaluate the change in terms of willingness to give up environmental quality:

$$\begin{aligned} \Delta W = W[V_1(y_1 - c_1, E + \Delta E, E^o), V_2(y_2 - c_2, E + \Delta E, E^o)] \\ -W[V_1(y_1 - c_1, E + \Delta E, E^o - CV_1^{E^o}), V_2(y_2 - c_2, E + \Delta E, E^o - CV_2^{E^o})] \\ = \sum_i W_i \cdot V_{E_i^o} \cdot CV_i^{E^o} \end{aligned} \tag{6}$$

where $V_{E_i^o}$ is the marginal utility individual i attributes to the other environmental good evaluated at some intermediate point $E_{im}^o \in [E^o, E^o - CV_i^{E^o}]$.

3 A numerical illustration

In order to provide a simple numerical illustration let us assume the following simple indirect (logarithmic Cobb-Douglas) utility functions:

$$V_i = \ln(y_i) + \ln(E) + \ln(E^o) \tag{7}$$

where commodity prices and other constant terms are suppressed. Let us use the following initial values: $y_1 = 10$, $y_2 = 50$, $E = 1$, and $E^o = 1$. We consider a project which improves environmental quality, i.e. E, from $E = 1$ to $E = 1.5$. The project is associated with some monetary costs borne by individual 1, $c_1 = 1$, while individual 2 escapes any costs, i.e. $c_2 = 0$. We will assume that the social welfare function is Utilitarian so that we simply sum utilities across the two individuals. For simplicity we assume full measurability of utility.

In table (1) we present the monetary evaluation of the considered project. We have evaluated the marginal utility of income at initial and final income

Item	LB:$V_{y_i} \cdot CV_i$	UB:$V_{y_i} \cdot CV_i$
Individual 1	$0.11 \cdot 2.33$	$0.15 \cdot 2.33$
Individual 2	$0.02 \cdot 16.67$	$0.03 \cdot 16.67$
ΔW	0.59	0.85

Table 1: Numerical illustration of the monetary approach, where LB means lower bound and UB means upper bound.

levels, respectively. To obtain an exact estimate ($\Delta W = 0.71$) we should have evaluated the marginal utilities of incomes at some intermediate points.

Let us next evaluate the project in terms of what we have termed the other environmental commodity, i.e. E^o. The outcome is summarized in table (2). A comparison of the two tables illustrates that we can use either money or an environmental asset to evaluate the project. In this sense we might choose either approach. However, both approaches have their disadvantages.

Consider first the monetary approach. Unless the utility distribution is optimal so that the social marginal utility of income is equal for all individuals we cannot sum their willingnesses to pay as is obvious from equation (5).

In the case of a payment in terms of an environmental asset the problem is that individuals preferences typically differ, a point stressed by, inter alia, Flores and Thacher (2002). In terms of table 2 one individual is willing to give up 0.26 units of good E^o while individual 2 is willing to give up 0.33 units. If it is a public good we cannot satisfy the wishes of both individuals. Either individual 2 comes out as a gainer or individual 1 comes out as a loser, depending on whether we reduce the quality of the asset by 0.26 units or 0.33 units. However, the fundamental problem with the approach seems to be that without knowledge of the social welfare function the numbers, i.e. 0.26 and 0.33 in our numerical example, don't make much sense. In particular, this seems to be the case when one individual is willing to pay while the other individual is worse off and hence needs a compensation, i.e. more of E^o.

Item	LB:$V_{E_i^o} \cdot CV_i^{E^o}$	UB:$V_{E_i^o} \cdot CV_i^{E^o}$
Individual 1	$1 \cdot 0.26$	$1.35 \cdot 0.26$
Individual 2	$1 \cdot 0.33$	$1.5 \cdot 0.33$
ΔW	0.59	0.85

Table 2: Numerical illustration of the environmental goods approach, where LB means lower bound and UB means upper bound.

4 Some further results

A possibly useful result is obtained if the project under evaluation is "small". Then if the sum of monetary compensating variations is strictly positive then gainers can compensate losers so that everyone gains from the project. In our simple two-individuals society we have:

$$\Delta W = W_1 \cdot V_{y_1} \cdot (dCV_1 + dk_1) + W_2 \cdot V_{y_2} \cdot (dCV_2 + dk_2) \tag{8}$$

where dCV_i denotes the compensating variation associated with an infinitesimally small project such that individual 1 gains while individual 2 loses from the project, and $-dk_1 = dk_2$ denotes a compensation. If it holds that $dCV_i + dk_i > 0 \; \forall i$ then the project satisfies the (weak) Pareto criterion, i.e. all individuals are (strictly) better off. This assumes, however, that compensation is actually paid. If the compensation is just hypothetical, then one individual will actually be worse off. In this sense hypothetical compensation involves a much stronger value judgement than actual compensation.

Turning to discrete or non-marginal projects, Boadway (1974) showed that even a pure redistribution in a perfect market economy is typically associated with a positive sum of compensating variations. This result is known as the Boadway Paradox[5] and is analyzed in detail by Blackorby and Donaldson (1990). Furthermore, compensation criteria typically fail to rank some social states, i.e. provide incomplete rankings; see Boadway and Bruce (1984) for a detailed discussion. Thus there are strong arguments against the use of of the sum of (unweighed) compensating variations in cost-benefit analysis, in particular for large projects. This is so at least if

[5] One way to state the problem is to say that we have a general equilibrium price vector $p*$ and equilibrium incomes y_i with the project. The vector $p*$ is not an equilibrium price vector for incomes $y_i - CV_i$, in general. This problem vanishes for the infinitesimally small project which is evaluated at initial or pre-project prices.

the distribution of welfare is non-optimal. If welfare distribution is optimal, the social marginal utility of income is equal across individuals so at least for a marginal project a positive sum of compensating variations (or equivalent variations) implies that social welfare has increased given the chosen social welfare function.

In any case, it does not seem possible to formulate any similar rules for the evaluation in terms of an environmental commodity, in general. The only exception, at least in terms of sufficient conditions, seems to be when individuals are equipped with identical utility functions, welfare distribution is optimal, and the project is marginal. Then a positive (negative) and uniform dCV^{E^o} in equation (6) indicates that the considered project is socially profitable (unprofitable); recall that in this case the unobservable social marginal utility of E^o is the same for all individuals implying that dCV^{E^o} is proportional to dW. Thus very strong assumptions are involved. Therefore, this and other similar approaches seem even less applicable than an approach based on monetary units.

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