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Environmental sustainability and cost-benefit analysis

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Abstract. Efforts to 'operationalize' a concept of sustainability into appraisal methods for practical decisionmaking have been few and generally unpersuasive. In this paper it is argued that this need not be the case if a set of environmentally compensating, or 'shadow', projects within an overall portfolio are used to ensure a sustainability objective of setting a constraint on the depletion and degradation of the stock of natural capital. This can be achieved through both a 'weak' and a 'strong' sustainability criterion. In both cases the resulting optimum differs from the efficient optimum of the conventional cost-benefit criterion, but the basic cost-benefit model remains intact.

1 Introduction

The extent to which cost-benefit analysis (CBA) can adequately account for environmental concerns is the subject of an extensive and controversial literature. Views range from the belief that it is a 'matter of time' before CBA succeeds in valuing the most significant environmental effects, to those that deny a pervasive role for the monetary evaluation of environmental gains and losses (Sagoff, 1988). An additional concern arises with respect to the distribution of gains and losses over time. It is widely thought that conventional procedures for discounting discriminate against future generations by (a) rapidly depleting exhaustible resources, (b) 'shifting the burden' of distant costs (for example, nuclear waste disposal) to future generations, and (c) not sanctioning investments with benefits that are subject to long gestation periods (for instance forestry).

In this paper we suggest a way of accommodating these concerns without entering the controversial area of the discount rate but with a full assault on the valuation problem.

CBA embodies intuitive rationality in that any course of action is judged acceptable if it confers a net advantage, that is, if 'benefits' outweigh 'costs'. What constitutes a gain or loss depends on the objective function chosen. Most CBA operates with a function based on economic efficiency, that is, any increase in total net benefits is desirable irrespective of the distribution of these benefits or the impact of the action on the noneconomic objectives. But this is only *one* objective function. It is widely used because economic efficiency is embodied in the very structure of the welfare economics developed over the last century. CBA is essentially the operational version of welfare economics. In principle, however, any other objective function can be chosen, or, more profitably, a *set* of objectives can be chosen.

Common parlance has it that CBA in which more than one objective is used is termed 'extended' CBA. Such terminology is neutral if the idea is to compare multiobjective CBA with the 'norm', that is, CBA based on economic efficiency alone. It is a misleading terminology if it is meant to imply that the basic structure of CBA is somehow overturned by the inclusion of other objectives.(1) One such

(1) Thus, it is sometimes suggested that incorporating a distributional objective into CBA leads to a fundamental modification. But this is not so. See Pearce (1986) and, for the context of developing countries, Little and Mirrlees (1974) and Dasgupta et al (1972).

additional objective that is often put forth is the notion that investment should be 'environmentally sustainable'; that is, it must ensure nondepreciation of the stock of natural environmental assets. In this paper we argue (a) that sustainability does have an economic interpretation, (b) that integrating the sustainability objective into CBA can be shown to leave the basic structure of CBA intact, but (c) that the resulting modifications to the basic theorems are of interest, and, we suggest, of importance.

2 The sustainability criterion

'Sustainable development' is a somewhat vague term popularized in the Brundtland report (WCED, 1987) but earlier espoused in the World Conservation Strategy (IUCN, 1980). It is typically taken to mean that the well-being of the current generation should not be advanced at the expense of future generations. *Within* a generation, sustainability also implies particular concern for the most disadvantaged in society. An economic interpretation of sustainable development is possible and focuses on the traditional concerns of economic efficiency and an equitable distribution of income. This interpretation involves the following sequence: (a) in order to ensure that future generations are not disadvantaged by the present generation, actual compensation of future generations by the present generation is required. This is a departure from the conventional hypothetical compensation requirements of cost-benefit analysis; (b) the form in which compensation takes place is via a transfer of capital assets; and (c) this 'capital compensation' requires that no less than the current capital stock, in terms of its value, be passed on to future generations. These requirements are spelled out in more detail in Maler (1989) and Warford and Pearce (1990).

The stock of capital may be interpreted as the combined total stock of man-made capital assets and environmental assets (soil, minerals, biomass, etc), or, more narrowly, as the stock of environmental assets only ('natural capital'). The former interpretation (for example, see Repetto, 1986) is relevant to the Hartwick-Solow rule which shows that reinvestment of the total 'rent' from exhaustible resource exploitation will secure a constant stream of consumption over time, which is thus 'intergenerationally fair'. Solow (1986) demonstrates that such a fairness rule is formally equivalent to keeping the stock of all capital constant. Basically, if an exhaustible resource, such as oil, is depleted, the profits, or 'rent', from depletion should be reinvested in other forms of capital (machinery, roads, and so on) so as to compensate for the decline in natural assets. Failure to do this may be consistent with intergenerational *efficiency* but is not consistent with intergenerational *equity*.

The narrow definition of the resource base in terms of environmental assets only, does not dispute the importance of man-made capital in the sustainable development process, but emphasizes the *nonsubstitutability* of many natural-resource functions by man-made capital. Notable among these are the life-support functions of natural environments in terms of biogeochemical cycles. In the narrower definition, then, natural capital is 'special' and this accounts for the requirement that it should not be degraded (Pearce et al, 1990). This suggests that sustainability can be introduced into CBA by setting a constraint on the depletion and degradation of the stock of natural capital.

'Constancy' of the natural capital stock can take on different meanings—interpretations in terms of constant *physical* capital stock and the constant *economic value* of that stock are common (Bishop, 1978; Page, 1977; Pearce et al, 1988). In constructing a sustainability criterion for CBA, we can be more specific: essentially, the objective of economic efficiency is modified to mean that all projects yielding net benefits should be undertaken subject to the requirement that environmental damage (that is, natural capital depreciation) should be zero or negative. However, applied at the level of each project such a requirement would be stultifying. Few projects would be feasible. At the programme level, however, the interpretation is more interesting. It amounts to saying that, netted out across a set of projects (a programme), the *sum* of individual damages should be zero or negative. That is, if E_i is the damage done by the ith project, we require that

$$\sum_i E_i \leqslant 0 . \qquad (1)$$

In such a formulation time is ignored. In the next section, we address the question directly and show that two formulations of the sustainability constraint emerge. Under weak sustainability it is the present value of $\sum_i E_i$, $\mathrm{pv}(\sum E_i)$, which is constrained to be nonpositive. Under strong sustainability $\sum E_i$ is constrained to be nonpositive for each period of time.

As it is not feasible to set $\mathrm{pv}(E_i)$ or E_i to be zero or negative for each project, but it is feasible to set $\mathrm{pv}(\sum E_i)$ or $\sum E_i$ to be nonpositive, the sustainability constraint amounts to including within any portfolio of investments one or more *shadow projects*, the aim of which is to compensate for the environmental damage from the other projects in the portfolio.[2]

$$\sum_t d_t \left[\sum_i (B_{it} - C_{it} - E_{it}) \right] > 0 , \qquad (2)$$

where B is nonenvironmental benefits, C is nonenvironmental costs, E is net environmental costs or benefits, t is time, and d_t is the discount factor.

The environmentally compensating project(s), j, would be chosen such that the inequality

$$\mathrm{pv}\left(\sum_j A_j \right) \geqslant \mathrm{pv}\left(\sum_i E_i \right) \qquad (3)$$

applies for the weak sustainability criterion, and the inequality

$$\sum_j A_{jt} \geqslant \sum_i E_{it} , \qquad \forall t \qquad (4)$$

applies for the strong sustainability criterion, where the net environmental benefits of the jth project, $A_{j1}, A_{j2}, ..., A_{jT}$, compensate for the damage done by the other projects. For the compensating projects, then, the normal CBA decision rule does not apply, although we would wish to minimize the cost of achieving the sustainability criterion.

In the following section we develop this approach further in a formal analysis of sustainability and CBA.

3 Analysis of sustainability and cost-benefit analysis

The traditional criterion for project appraisal is that the discounted benefit of each project i should equal or exceed its costs; that is,

$$\sum_t d_t [B_{it} - C_{it}] \geqslant 0 , \qquad i = 1, ..., n . \qquad (5)$$

where B_{it} is the benefits of the ith project in time period t, C_{it} is its costs in that time period, and d_t is the discount factor, equal to $1/(1+r)^t$. We assume a finite time horizon $[0, T]$.

(2) The idea of a shadow project is suggested by Klaassen and Botterweg (1976) in what appears to be a neglected paper.

For a portfolio of projects, inequality (5) becomes

$$\sum_t d_t \left[\sum_i (B_{it} - C_{it}) \right] \geqslant 0 . \tag{6}$$

As argued by Markandya and Pearce (1988a; 1988b), the 'correct' approach to 'internalizing' any environmental damage caused by a project might simply be to adjust net benefits, $B_{it} - C_{it}$, to include the costs of such damage. That is, if E_{it} is defined as the costs of environmental damage generated by the ith project at time period t, then inequalities (5) and (6) become, respectively:

$$\sum_t d_t [B_{it} - C_{it} - E_{it}] \geqslant 0 , \qquad i = 1, ..., n , \tag{7}$$

and

$$\sum_t d_t \left[\sum_i (B_{it} - C_{it} - E_{it}) \right] \geqslant 0 . \tag{8}$$

Although criteria (7) and (8) are effective in 'internalizing' the environmental costs of projects in the appraisal process, they are insufficient for overall environmental 'sustainability'. For example, criteria (7) and (8) could hold, while at the same time in some time periods, the total environmental damage costs generated by the portfolio of n projects could be greater than zero, that is,

$$\sum_i E_{it} > 0 , \qquad \text{for some } t . \tag{9}$$

Thus, the portfolio as a whole is continuing to degrade the environment. Over the long run, the cumulative environmental degradation (for example, soil erosion, deforestation, waste accumulation) may severely degrade or deplete the resource base.(3)

Consequently, to ensure that a portfolio of projects does not undermine the sustainability of the resource, one must adopt an explicit constraint. As noted in the previous section, there are two possibilities—a 'weak' and a 'strong' sustainability condition. The weak sustainability condition is that the discounted present value of the environmental damage costs across all projects is nonpositive, whereas the strong sustainability criterion requires that the net environmental costs across all projects be nonpositive for each and every time period. These are represented mathematically in inequalities (11) and (12).

The planning criteria for each of the sustainability conditions can be expressed as follows. In addition to the portfolio of projects, $i = 1, ..., n$, there is a portfolio of environmentally mitigating, or shadow, projects, $j = 1, ..., m$. Each project j in this portfolio has associated with it a cost profile, $C_{j1}, C_{j2}, ..., C_{jT}$; a benefit profile, $B_{j1}, B_{j2}, ..., B_{jT}$; and a set of net environmental benefits, $A_{j1}, A_{j2}, ..., A_{jT}$. For the sustainability criterion to be met in an optimizing framework, the sum of the returns from *all* projects must be maximized, subject to the net environmental damages being nonpositive:

$$\underset{Q_{it},\, Q_{jt}}{\text{maximize}} \sum_t d_t \left[\sum_i (B_{it} - C_{it} - E_{it}) \right] + \sum_t d_t \left[\sum_j (B_{jt} - C_{jt} + A_{jt}) \right] , \tag{10}$$

(3) The constraint here is formulated in value terms for environmental damage. This may not be the relevant concept if it is in fact the physical damage that one wants to restrict for each type of degradation. The analysis presented here can easily be extended to the case of several environmental constraints, but the only implication as far as this presentation is concerned is that the mathematics would become more complicated.

subject to the condition

$$\sum_t d_t \left(\sum_i E_{it} - \sum_j A_{jt} \right) \leqslant 0 \,, \qquad \text{for weak sustainability}, \tag{11}$$

and

$$\left(\sum_i E_{it} - \sum_j A_{jt} \right) \leqslant 0 \,, \qquad \forall t, \text{ for strong sustainability}, \tag{12}$$

where each ith and jth project is defined by its activity level, Q_{it} and Q_{jt}, respectively, and the functions B_{it}, C_{it}, E_{it}, and A_{it} are differentiable in Q.(4) Assuming $Q_{it} > 0$, $Q_{jt} > 0$, and $P_t > 0$, for all i, j, and t, we can write the Kuhn–Tucker maximization conditions of the Lagrangean formed for the weak sustainability criterion (11) as

$$\sum_i \frac{1}{\mathrm{d}Q_{it}} (\mathrm{d}B_{it} - \mathrm{d}C_{it} - E_{it} - P_t \mathrm{d}E_{it}) = 0 \,, \qquad \forall t, \tag{13}$$

and

$$\sum_j \frac{1}{\mathrm{d}Q_{jt}} (\mathrm{d}B_{jt} - \mathrm{d}C_{jt} + \mathrm{d}A_{jt} + P_t \mathrm{d}A_{jt}) = 0 \,, \qquad \forall t. \tag{14}$$

P_t is the Lagrangean multiplier, the value of which will depend, in general, on all the Qs and d_t. It can be interpreted as the 'price' of the sustainability constraint. Its value is equal to the user cost of degrading the environment, or alternatively, the marginal net present value of all the projects from 'relaxing' the constraint.

As $(\mathrm{d}B_{it} - \mathrm{d}C_{it})/\mathrm{d}Q_{it}$ is the marginal net benefit ($B_{it}^{\text{m.net}}$) of the ith project and $\mathrm{d}E_{it}/\mathrm{d}Q_{it}$ is its marginal cost of environmental damage ($C_{it}^{\text{m.env}}$), inequality (12) can be rearranged as

$$\sum_i \frac{B_{it}^{\text{m.net}}}{C_{it}^{\text{m.env}}} = (1 + P_t) \,, \qquad \forall t. \tag{15}$$

Equation (15) expresses that the total net marginal benefits across the n projects should be equal to their total net marginal cost of environmental damage, *plus* a factor λ_t $(= P_t \sum_i C_{i,t}^{\text{m.env}})$ which represents a premium arising from the sustainability criterion. If there were no constraint, it would be rational to equate the net benefits of the portfolio to its environmental costs; that is, the optimal solution reduces to the standard efficiency CBA criterion (8). Figure 1(a) depicts this optimum for the portfolio, which occurs at total activity level Q_{nt}^{*}. However, if the factor P_t is positive, implying that the 'weak' sustainability criterion (11) is enforced, then a new curve in figure 1(a) is drawn, which represents the environmental costs plus a 'sustainability' premium.(5) The new optimum, Q_{nt}^{**}, is to the left of the unconstrained one, Q_{nt}^{*}, implying a lower level of total activity.

Similarly, if we define $(\mathrm{d}B_{jt} - \mathrm{d}C_{jt})/\mathrm{d}Q_{jt}$ as the marginal net benefits ($B_{jt}^{\text{m.net}}$) of the jth environmentally compensating project, and $\mathrm{d}A_{jt}/\mathrm{d}Q_{jt}$ as its marginal environmental benefits ($B_{jt}^{\text{m.env}}$), equation (14) can be rewritten as

$$\sum_j \frac{-B_{jt}^{\text{m.net}}}{B_{jt}^{\text{m.env}}} = (1 + P_t) \,, \qquad \forall t. \tag{16}$$

Thus, as depicted in figure 1(b), rule (16) indicates that sufficient environmentally compensating projects, j, should be chosen to ensure that their total (negative)

(4) For expository purposes, it is assumed that Q varies freely from period to period, although this may not be likely. It is also assumed that the projects selected are fixed, that the functions A(.) and B(.) are concave, and that the functions C(.) and E(.) are convex.

(5) On the idea of a sustainability premium, see Pearce (1988).

marginal net benefits equal their total marginal environmental benefits plus a 'sustainability' premium λ_t $(= P_t \sum_j B_{jt}^{\text{m.env}})$. This premium is the social value of ensuring that the environmental improvements generated by the m projects compensate for the environmental damages inflicted by the other n projects in the combined portfolio $(m+n$ projects). As shown in figure 1(b), when this constraint is binding, the total activity level of the environmentally compensating projects (Q_{mt}^{**}) is higher than the unconstrained optimum (Q_{mt}^{*}).

Two points should be noted about the above analysis. First, when the premium λ_t is not positive, the returns to the m shadow projects are sufficient to net out all environmental damage, even though they are operating at their unconstrained maximizing levels. In that event there would be no need for these environmentally compensating projects to be justified as 'shadow projects' but as ones that were valid in their own right, as indicated by the CBA criterion (8). The second point is that when the sustainability premium is positive, the shadow projects individually may not satisfy the traditional appraisal criterion, as given in equation (5), or even the modified rule expressed in inequality (7). This is clear from equation (16). A shadow project could have a negative net present value, but its output of A_{jt} could be so great as to justify the project in terms of its contribution to fulfilling the sustainability constraint.

Under the strong sustainability criterion (12), it can easily be confirmed that the Kuhn-Tucker maximization conditions become

$$\sum_i \frac{B_{it}^{\text{m.net}}}{C_{it}^{\text{m.env}}} = \frac{d_t + P_t}{d_t} = 1 + P_t(1+r)^t, \qquad \forall t, \tag{17}$$

and

$$\sum_j \frac{-B_{jt}^{\text{m.net}}}{B_{jt}^{\text{m.env}}} = \frac{d_t + P_t}{d_t} = 1 + P_t(1+r)^t, \qquad \forall t, \tag{18}$$

(where r is the rate of discount) for Q_{it}, Q_{jt}, and P_t all greater than 0. Equations (17) and (18) are analogous to equations (15) and (16), respectively, but state that the sustainability premium grows exponentially with time. Equations (17) and (18), along with the constraint (12), are a system of equations that determine the values of $P_1, P_2, ..., P_T$; $Q_{i1}, Q_{i2}, ..., Q_{iT}$; and $Q_{j1}, Q_{j2}, ..., Q_{jT}$ for all i and j. In order to find

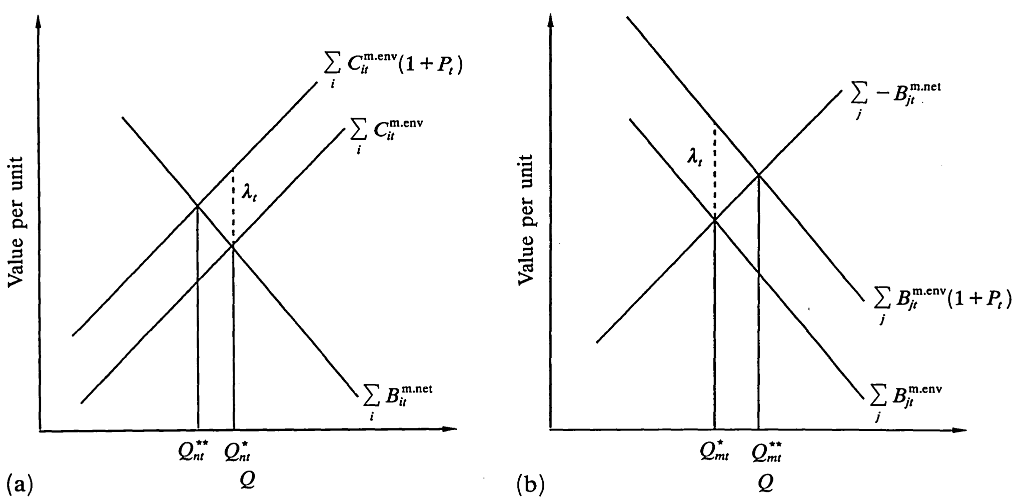

Figure 1. The sustainability optimum for (a) environmentally depleting projects, and (b) environmentally compensating projects.

out how the values of P_t change with d_t and how the sustainability premium changes with r, one has to carry out a full comparative statics exercise on this system of equations. Unfortunately, no general results appear to be available, and more structure would have to be put on the problem before results of this kind could be obtained.

4 Conclusion

The above analysis indicates that both a weak and a strong sustainability criterion can be easily incorporated into CBA through the use of 'environmentally compensating' projects. This is in contrast to a widely suggested alternative approach, in which the discount rate for environmentally beneficial projects is lowered relative to the rate for those that generate environmental damage (Kula, 1984; 1985). It is possible to show that adjusting the discount rates for some 'environmental risk premium' can produce similar results to those suggested here, but the adjustments are complex, and the actual determinationof the risk premium for damaging projects (or the discount for beneficial projects) is liable to generate impossible informational demands (Markandya and Pearce, 1988a; 1988b). Yet another suggestion, that *all* projects should attract a lower discount rate can actually be counterproductive to the basic idea of maintaining natural capital stocks. This is because lower discount rates encourage a larger *total* of investment and this will 'drag' through the system more materials and energy and hence more waste (Markandya and Pearce, 1988a; 1988b).

There is therefore an attraction to using a procedure which avoids adjusting discount rates. The 'sustainability constraint' or 'compensating project' approach achieves this aim. It has a cost in that, in order to know if environmental assets are being 'held constant, it is necessary to value the assets. Elsewhere we have suggested that valuation procedures have advanced considerably in recent years and can be advanced much further (Barbier, 1988; Pearce and Markandya, 1989). We conclude that the 'compensating project' approach is more profitable as a way of modifying CBA practically. The burden then falls on the proper economic valuation of the environmental impacts, E_{it}.

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