QUADERNI

Università degli Studi di Siena
DIPARTIMENTO DI ECONOMIA POLITICA

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Welfare Indices and Environmental Accounting: A Critical Survey

n. 262 - Settembre 1999

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* We thank Geoffrey Heal and Kirk Hamilton for very useful discussion on this subject. All remaining errors are only ours.

1. Introduction[1]

One of the most controversial issues in National Income Accounting is the research of an appropriate welfare indicator. The Gross National Product (GNP) is often used for this purpose. However, as El Serafy and Lutz (1989, p.1) point out, the concept of welfare "is much broader than a monetary measure of income", since it encompasses many aspects of human well-being that cannot be measured in monetary terms.

One of the main shortcomings of GNP is that it does not adequately reflect the depletion and degradation of natural resources, which makes it diverge from a true measure of income. For this reason the Net National Product (NNP), which takes capital depreciation into account, has been suggested as a more suitable welfare measure. As it is well known, NNP is defined as follows:

$$NNP = C + I + (X-M)$$

where C = consumption, I = net investments, X = exports and M = imports.

If we assume that welfare depends on consumption possibilities, then the first term on the right-hand side can be interpreted as current well-being from production today, and the remaining two terms as future consumption possibilities from current investment activities. More precisely, net investments represent the increase in future production capacity of the economy, while net exports (X-M) imply an accumulation of claims on other countries that will eventually lead to a larger amount of imported consumption goods in the future.

As Mäler (1996, p.3) has pointed out, this definition of NNP is still a rather narrow notion of welfare since it includes only consumption goods that are bought and sold on the market. In fact, current welfare is also influenced by non-market goods and services such as environmental amenities. Similarly, future wellbeing depends on variation of assets that are not transacted on the market, such as depletion of exhaustible resources and net changes in the stock of renewable resources. These considerations raise the following issue: how can we adjust national accounts to reflect the economic depreciation

[1] Although this paper was jointly written, Simone Borghesi takes responsibility for section 2 and Silvia Tiezzi for section 4.

of natural resources? In this regard, we can distinguish two main approaches that have tried to answer this question. On one hand, economic theorists have used optimal control theory to derive a correct measure of environmental degradation in mathematical terms. On the other, national accountants have extended the System of National Accounts (SNA) in the form of satellite accounts, the main result being the System of Economic and Environmental Accounts (SEEA) proposed by the United Nations in 1993.

The difficulty in translating the adjustments suggested by economic theory into an accounting tool can probably explain why the theoretical approach has often received little attention at empirical level, so that "the various groups proposing answers are not communicating with each other" (Mäler 1996, p.4).

The aim of the present paper is to make a contribution that can enhance communication between these different groups. For this purpose, we will first try to explain the arguments put forward by economic theory to arrive at a correct welfare measure and then investigate how the adjustments emerging from the theoretical analysis can actually be computed. We will not examine, instead, the existing macroeconomic accounting tools that could be used as a framework to include these adjustments. This is because a proper treatment of the integration between environmental and economic accounts would require a detailed analysis that is beyond the scope of the present work.

The structure of the paper is as follows. Section 2 provides a critical survey of some of the main contributions proposed in the optimal control theory to compute the economic depreciation of natural resources analytically and thus arrive at a correct welfare measure. These computations are based on shadow or true scarcity prices. However, observed prices generally differ from scarcity prices because of distortions in the economy that make it diverge from the optimal path. Therefore, Section 3 examines the issue of the accounting prices that can be used to determine the economic depreciation of natural capital. Section 4 deals with the implementation of the adjustments suggested by the theory in the national accounts. In particular Section 4.1 examines the treatment of environmental defensive expenditures since different theoretical models take different approaches to this issue. Section 4.2 deals with the estimation of marginal environmental damages and costs. We consider two different methodologies that could be applied to obtain a rough, first approximation of environmental damages and costs at aggregate level, taking into account that the microeconomic evaluation methodologies are too difficult to implement at national level. Section 4.3 reviews the methodologies proposed to calculate natural resource depreciation. Section 5 contains some concluding remarks.

2. The adjusted NNP as a true welfare measure: the theoretical debate in the literature

2.1 The Weitzman model: NNP as welfare measure and the interpretation of the current-value Hamiltonian

Surprisingly enough, most of the debate on environmental accounting started with a seminal paper by Weitzman (1976) which contained no reference to environmental issues. In his paper Weitzman asked why NNP, defined as consumption plus net investment, could be regarded as a good measure of welfare, as commonly accepted by many authors before him. In fact, according to Samuelson's definition of welfare as present value of consumption, consumption and not capital formation is the ultimate aim of economic activity. Why then include investments in the measure of welfare, as NNP does?

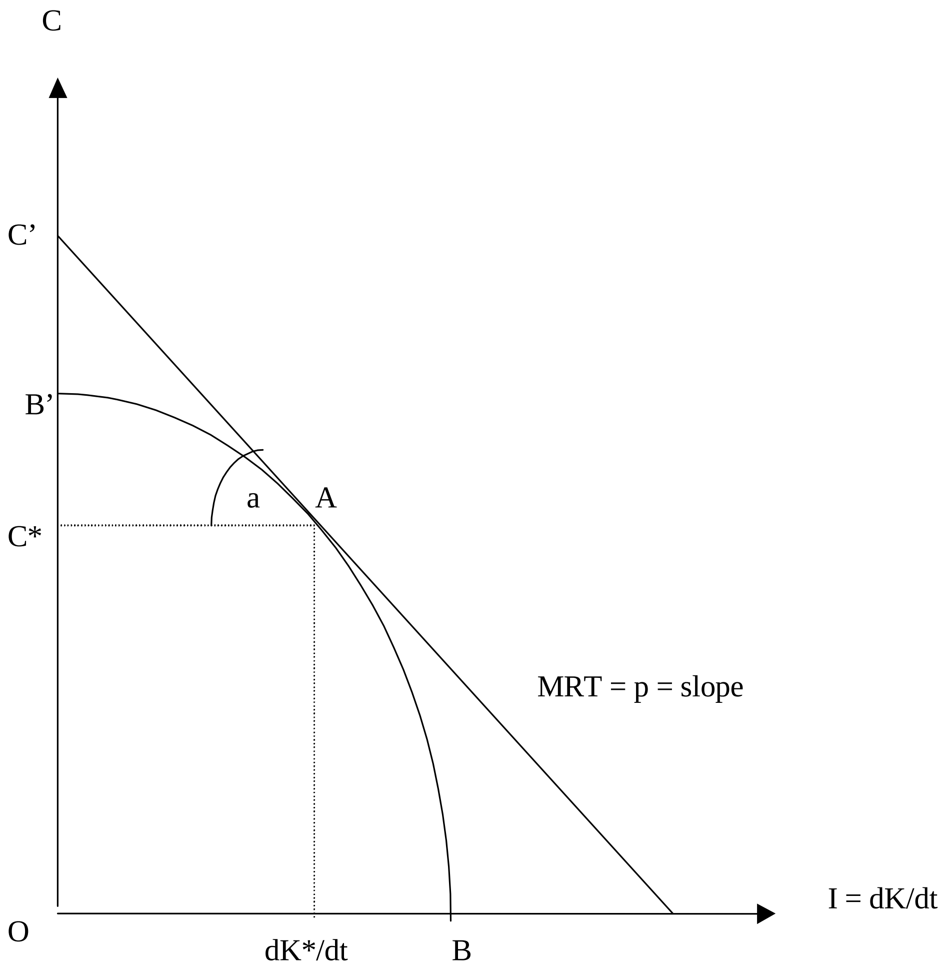
As Weitzman himself says (1976, p.159), "if all investments were convertible into consumption at the given price-transformation rates" the maximum consumption which could be maintained for ever without running down the capital stock would be just the NNP, as conventionally measured:

(1) $NNP = C^* + p(dK^*/dt)$.[2]

However, it is not possible to convert in reality all investments into consumption. Therefore, $C^* + p(dK^*/dt)$ is not feasible and - a fortiori - not permanently maintainable. To show why this is the case, Weitzman used a very simple diagram (Figure 1).

[2]The stars indicate the optimal values of the variables in question.

Figure 1



Source: Weitzman, 1976

legend: MRT = marginal rate of transformation

The distance OC' is the geometric equivalent of real NNP. In fact it is:

(2) OC' = OC* + C*C'

(3) p = tg(a) = C'C*/AC*

where tg(a) is the tangent of the angle a (Figure 1). Therefore, from (3):

C'C* = p(AC*) = p(dK*/dt)

which, substituted back into (2), yields:

OC' = C* + p(dK*/dt) = NNP.

Since the economy can only reach the points along the production possibility frontier BB’, OB’ is "the largest permanently maintainable level of consumption that can *actually* be obtained", while OC' is a "*strictly hypothetical* consumption level at the present time" (Weitzman, 1976 p. 159).

At first sight, the fact that NNP corresponds to an unfeasible consumption level seems to imply that it cannot be taken as a measure of welfare. However, from a deeper insight into the nature of NNP, Weitzman shows that this notion can be viewed as a welfare measure, although it is a hypothetical consumption level and not a real trajectory of an economic system. In fact, it can be proved that:

$$(4)\quad \int_t^\infty C^*(s)\, e^{-r(s-t)} ds = \int_t^\infty \left[C^*(t) + p(t)\frac{dK^*}{dt}(t) \right] e^{-r(s-t)} ds$$

Equation (4) states that the present value of consumption along an optimal path (the term on the left-hand side) is equal to the present value of NNP, if maintained constant from time t onwards (the term on the right-hand side). In other words, as Weitzman claims (1976, p.160) "the maximum welfare actually attainable from time t on along a competitive trajectory is exactly the same as would be obtained from the hypothetical constant consumption level" given by NNP. The NNP is thus a "proxy for the present discounted value of future consumption" (Weitzman 1976, p.156) and the "*stationary equivalent of future consumption*" (Weitzman 1976, p.160).

Beside this notion of NNP, Weitzman's theoretical framework provides another possible interpretation of the concept: "NNP is what a social planner would choose to maximise" (Atkinson et al., 1999 p.34). This can immediately be verified by examining the structure of the optimisation problem. As mentioned above, in accordance with Samuelson's definition of welfare, Weitzman takes the present value of consumption as the objective function to be maximised. This is equivalent to assuming a utilitarian framework, with linear utility function:

(5) U(C(t)) = C(t).

Therefore, a hypothetical social planner would have to solve the following optimisation problem:

(6) $$\underset{C(t)}{Max} \int_{t}^{\infty} C(t)\, e^{-rt} dt$$

subject to:

(7) $$(C(t), \frac{dK}{dt}(t)) \in S(K(t))$$

(8) $$K(0) = K_0$$

where S(K(t)) is the production possibility set at time t represented in Figure 1 and K_0 the stock of initial capital available at time 0.

Equation (7), which represents a condition of efficiency in production, can also be written as an explicit function:

(9) $$\dot{K}(t) = \frac{dK}{dt}(t) = f(C(t))$$

Along the optimal path, the current value Hamiltonian $H_c(t)$ corresponding to the above maximisation problem is therefore:

(10) $$H_c(t) = C^*(t) + p(t) f(C^*(t)) = C^*(t) + p(t)\dot{K}^*(t)$$

where the costate variable p(t) is the shadow value of capital.

Equation (10) defines an index that is linear both in consumption and in the investment level. Since the price of consumption is taken as numeraire in the model (i.e. it is equal to one), this linear index is equal to the NNP as measured along an optimal competitive trajectory. Hence, in the simple maximisation problem set forth by Weitzman, *the current value Hamiltonian is the NNP*.

2.2 Extending Weitzman's framework to the environmental issue: the Hartwick model

As Pemberton and Ulph (1998, p.1) have pointed out, Weitzman's conclusions hold "in the context of the particular model considered in the paper", as they heavily hinge on specific assumptions. In this regard we can identify three main hypotheses which distinguish Weitzman's model[3]:

(i) a *linear utility function*

(ii) a *fixed interest rate* on the consumption good.

(iii) an explicit *definition of income* as the maximum feasible NNP, namely:

(11) $$Y(K,p) = \max_{(C,I)\in S(K)} [C + pI]$$

Despite the specific features of Weitzman's framework, many authors have tried to extend his analysis to the environmental context to determine how the NNP should be adjusted to incorporate the depreciation of natural resource stocks. One of the main contributions in this sense is the Hartwick model (1990).

Hartwick examines the optimal growth of an economy with natural resources, which he divides into three main categories: exhaustible resources, renewable resources and environmental capital. Following Weitzman's approach, Hartwick also assumes a utilitarian objective function, but he does not make any specific assumption about the linearity of the function. This raises the following question: if the utility function is non-linear in consumption (C) how can the current value Hamiltonian be linear in its arguments and thus equal to the NNP? [4]

To answer this question, let us first examine Hartwick's maximisation problem and focus attention on the first of the three categories that he investigates: exhaustible resources.

2.2.1 Exhaustible resources

In the case of an economy that relies on an exhaustible resource for production, the optimisation problem is as follows:

[3] Another assumption which plays an important role is the fact the economy is supposed to be closed. Due to space constraints, we will not examine the case of an open economy in the present paper.

[4] Recall, from (1), that the NNP is defined as a measure that is linear in its arguments (consumption and investment).

(12) $Max\int_0^\infty U(C)e^{-\rho t}dt$

(13) $s.t.\ \dot{K} = F(K,L,R) - C - f(R,S) - g(D,S)$

(14) $and\ \ \dot{S} = D - R$

where:

ρ = intertemporal discount rate

S = stock of the exhaustible resource

R = flow of the exhaustible resource

D = discoveries of new stock of the resource

K = physical capital

L = labour

f(R,S) = cost of resource extraction

g(D,S) = cost of resource exploration.

Observe that (13) corresponds to equation (9) in Weitzman's optimisation problem, but we now have an additional state variable (S) and thus also the additional constraint (14) that determines how the exhaustible resource changes over time. The current value Hamiltonian of the above problem is:

(15) $H_c(t) = U(C) + \phi(t)[F(K,L,R) - C - f(R,S) - g(D,S)] + \varphi(t)[D - R]$

If the utility function is non-linear in consumption, the current value Hamiltonian will also be non-linear and thus the equivalence highlighted by Weitzman between H_c(t) and NNP no longer holds.

However, Hartwick takes a linear approximation of the utility function around the point $C=C_0$:

(16) $U(C) = U(C_0) + U_C(C - C_0)$

where $U_c = \left.\frac{dU}{dC}\right|_{C=C_0}$

Substituting (16) into (15), we get:

(17) $H_c(t) = U_c C + \phi(t)\underbrace{[F(K,L,R) - C - f(R,S) - g(D,S)]}_{\dot{K}} + \varphi(t)\underbrace{[D - R]}_{\dot{S}}$

where the term $U(C_0)+U_C C_0$ has been omitted since the solution to an optimisation problem is invariant with respect to a constant.[5]

Notice that the marginal utility level computed at the expansion point $C=C_0$ (what he calls U_C) is obviously constant. This has two important consequences.

In the first place, the current value Hamiltonian is linear in C, I and $\dot{S}$ and is equal to the aggregate value of all quantities in the economy (the flow of consumption and the stocks of man-made and natural capital), each valued at its shadow price (1, $\phi(t)$ and $\varphi(t)$ respectively). Therefore, Hartwick takes a linear approximation of the utility function to make his framework analogous to that of Weitzman and thus extend the equivalence of current value Hamiltonian and NNP to his own model. In the second place, the fact that U_C is constant allows Hartwick to justify measuring NNP in monetary terms. In fact, dividing H_C by U_C we get what Hartwick (1990, p.293) calls the "dollar-value" expression for NNP:[6]

$$(18)\quad \frac{H_c(t)}{U_c} = C + \frac{\phi(t)}{U_c}\dot{K} + \frac{\varphi(t)}{U_c}\dot{S}$$

From the first-order conditions we have:

$$(19)\quad Uc = \phi(t)$$

$$(20)\quad \varphi(t) = [F_R - f_R]\phi(t)$$

where F_R is the marginal productivity of the resource (equal to the resource price in equilibrium) and f_R is its marginal cost of extraction.

Substituting (19) and (20) into (18), it yields:

$$(21)\quad \frac{H_c(t)}{U_c} = C + \dot{K} - [F_R - f_R][R - D]$$

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[5] The linearisation of the utility function that we present here is slightly different from the method followed by Hartwick. This is because we find Hartwick somewhat unclear on this specific point. In fact, after defining the current value Hamiltonian (equation 15) and the corresponding first-order conditions, Hartwick (1990, p.293) claims: "Let us use a linear approximation $U(C)=U_C C$". In fact, this is not a linear approximation of the utility function unless we take the Maclaurin expansion (around C=0), rather than the Taylor expansion (around $C=C_0$). However, even if one takes the Taylor expansion (as we do above), the constant terms do not affect the optimisation problem, therefore they can be omitted in equation (17). This is probably what Hartwick means with the statement above when he takes only $U_C C$ into account.

[6] From the first order conditions, U_c equals $\phi(t)$, that is, the marginal utility of income. Since the current value Hamiltonian is measured in utility terms, dividing $H_c(t)$ by U_c is equivalent to dividing utility by the marginal utility of income, which yields an index measured in income or monetary terms.

The last addendum on the right-hand side is the correction term that should be measured in green national accounts to quantify the economic depreciation of an exhaustible resource.[7] The term F_R-f_R is obviously the Hotelling rent. To achieve a correct measure of welfare, we should therefore deduct the resource rents given by the product of the reduction in the stock of the exhaustible resource times its shadow price, from conventional measures of NNP (as defined in equation 1).

Pemberton and Ulph (1998) have recently criticised Hartwick's approach for two main reasons. In the first place, they point out that the equivalence of NNP to the Hamiltonian is derived in Weitzman's model from a specific definition of income (assumption (iii) on p.5), whereas Hartwick does not give any explicit definition of income in his paper. In the second place, they argue that the linearisation of the utility function is an "ad hoc" assumption to get a constant marginal utility and thus make the model analogous to that of Weitzman who assumed a linear utility function (assumption (i) on p.5).

To overcome these drawbacks that affect Hartwick's contribution, Pemberton and Ulph assume a non-linear (strictly concave) utility function and solve the optimisation problem without taking any linear approximation of the function. Moreover, unlike Hartwick, they give an explicit definition of income, taking the Hicksian notion as starting point, and try to derive an adjusted measure of NNP that is consistent with that notion in the case of exhaustible resources. In this way Pemberton and Ulph derive the corrected measure of NNP in a more general framework and base it on a notion of income that is well-founded in the economic theory. However, the adjusted NNP obtained by Hartwick is still valid. In fact, Pemberton and Ulph (1998, p.7) show that along the optimum path it is:

$$(22)\quad Y^*{}_t = C^*{}_t + \frac{dK_t{}^*}{dt} - x^*{}_t R^*{}_t$$

where Y_t denotes the income level, R_t the resource rent and x_t the flow rate of utilisation of the exhaustible resource at time t.[8] It is easy to verify that the above expression corresponds to equation (21), what they call the National Income Rule suggested by

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7 In steady state, this term is obviously zero since $\dot{S} = 0$.

8 Note that x^*_t and R^*_t in equation (22) correspond to [F_R-f_R] and [R-D] respectively in equation (21).

Hartwick. Therefore, the authors conclude that although Hartwick used a *flawed method of correction* of NNP, the *correction term* he obtained is still *valid*.

Hartwick's model can obviously be extended to other cases of exhaustible resources by changing the initial assumptions slightly. Hamilton (1994), for instance, examines the case of a homogeneous exhaustible resource, having N heterogeneous resource deposits with different extraction costs f_i (e.g. oil). As it can be easily verified, in this case we get:

$$(23)\quad NNP = C + \dot{K} - \sum_{i=1}^{N} (F_R - f_{Ri}) R_i$$

where f_{R_i} is the marginal extraction cost in deposit i and R_i is the amount extracted in the same deposit.

Thus, if we have N different deposits, the correction term to be subtracted is the sum of the rents on each resource deposit.

A second modification of Hartwick's analysis can be obtained by changing the discovery cost function g. Hamilton (1994) shows that if g depends on the cumulative discoveries of the exhaustible resource rather than on the remaining stock S, a different correction term emerges from the model. In fact, it is:

$$(24)\quad NNP = C + \dot{K} - (F_R - f_R)R + g_D D$$

If we compare this expression with equation (21), we see that the new discoveries are now valued at their marginal cost (g_D) rather than at the Hotelling rental rate ($F_R - f_R$).

2.2.2 Renewable resources

So far we have considered the case of an exhaustible resource. But how should NNP be adjusted to account for the depreciation of a renewable resource?

Let us call Z the stock and E the level of exploitation of such a resource, say fish. In this case, Hartwick (1990) argues that the flow E should be treated as a source of utility as it may be consumed directly by the representative agent. Therefore, he sets out the following central planning problem:

$$(25)\quad Max \int e^{-\rho t} U(C, E)$$

$$(26)\quad s.t.\ \dot{K} = F(K, L) - C - f(E, Z)$$

$$(27)\quad and\ \dot{Z} = r(Z) - E$$

where $f(E,Z)$ is the extraction cost of the renewable resource and $r(Z)$ is its rate of growth. The corresponding current-value Hamiltonian is:

(28) $H_c(t) = U(C,E) + \phi(t)\left[F(K,L) - C - f(E,Z)\right] + \varphi(t)\left[r(Z) - E\right]$

Following the procedure described above for an economy with an exhaustible resource, Hartwick (1990) replaces the utility function with its linear approximation[9] and then divides $H_c(t)$ by the constant term U_c to express the NNP in dollar value terms. This yields:

(29) $$\frac{H_c(t)}{U_c} = C + \frac{U_E}{U_c}E + \frac{\phi(t)}{U_c}\dot{K} + \frac{\varphi(t)}{U_c}\dot{Z}$$

From the first-order conditions:

$$Uc = \phi(t)$$

$$\varphi(t) = Uc\left[\frac{U_E}{Uc} - f_E\right]$$

substituting into (29) we obtain the accounting rule for the case of renewable resources, that is:

(30) $$\frac{H_c(t)}{U_c} = C + \dot{K} + \frac{U_E}{U_c}E + \left[\frac{U_E}{Uc} - f_E\right]\dot{Z}$$

where $\frac{U_E}{U_C}$ is the market price of the renewable resource and f_E its marginal extraction cost (e.g. the cost of fishing one additional fish). As in the case of any other capital good, the adjustment of NNP to account for renewable resources is therefore in rental form (i.e. price minus marginal cost). More precisely, traditional NNP ($C + \dot{K}$) should be corrected by adding the value of the flows of the renewable resource and the change in its stock valued at the rental rate.[10]

[9] The considerations pointed out in footnote 5 also apply in the present case, the only difference being that utility is now a function of two variables.

[10] As Hartwick points out (1996, p.295), the change $\dot{Z}$ in the resource stock is probably negative in a world where both population and income grow substantially over time. Hence, the last term in equation (30) measures the economic depreciation of the renewable resource and it should be netted-out from NNP to get a true measure of national income.

2.2.3 Environmental capital goods and pollution

Let us now turn to the third category of natural resources examined by Hartwick: the environmental capital goods, such as airsheds and watersheds, the value of which is reduced by pollution. Hartwick assumes that there exists an *indirect* mechanism of pollution control via production: higher production levels imply higher pollution that in turn reduces the output Y for a given level of labour and capital. The production function is then:

(31) $Y = F(K, L, X)$

where X is the pollution stock and dF/dX < 0.

Nature tends to absorb part of the pollution stock X in the atmosphere, b being the natural rate of absorption. Given these assumptions, the equation of motion of X can be written as follows:

(32) $$\dot{X} = \gamma F(K, L, X) - bX$$

where γ is the ratio at which production increases pollution.

The social planner is now confronted with the following dynamic maximisation problem:

(33) $$Max \int_0^{\infty} e^{-\rho t} U(C) dt$$

(34) $$s.t. \;\; \dot{K} = F(K, L, X) - C$$

(35) $$and \;\; \dot{X} = \gamma F(K, L, X) - bX$$

Replacing the utility function by its first order approximation and the costate variables by the corresponding first order conditions, Hartwick ends up with the following corrected measure of NNP in monetary terms:

(36) $$\frac{H_c(t)}{U_c} = C + \dot{K} + \left[\frac{\rho - F_K}{\gamma F_K} \right] \dot{X}$$

where F_K is the marginal productivity and γF_K is the marginal pollution of one additional unit of capital.

As Hartwick points out, the reciprocal of γF_K is the increase in man-made capital foregone because of pollution, which reduces the economy’s productivity. Thus, in the present case, the depreciation term is the increase in the stock of pollution ($\dot{X} > 0$) multiplied by the negative effect of this increase on the investments in physical capital ($1/\gamma F_K$).

Besides this indirect control mechanism "via the output decision of the producers" (Hartwick 1990, p.298), pollution can also be controlled *directly* via abatement expenditures. The cost f of these expenditures, which depends on nature's capacity b to absorb pollution, reduces the amount of output left for investments:

(37) $\dot{K} = F(K, L, X) - C - f(b)$

Replacing equation (34) with (37) in the optimisation problem and solving as described above, Hartwick gets:

(38) $\frac{H_c(t)}{U_c} = C + \dot{K} - \frac{f'(b)}{X}\dot{X}$

The higher the natural rate of absorption b (that is, the faster pollution evaporates by natural regeneration of environmental capital), the higher the marginal cost of increasing b by investing in abatement capital. Hence:

$f'(b) > 0$ which implies $-\frac{f'(b)}{X}\dot{X} < 0$.

If pollution is increasing over time ($\dot{X}$ >0), we should therefore deduct from conventional NNP the cost of reducing pollution by $\dot{X}$ or equivalently the investment in physical capital foregone ($f'(b)$) to invest in abatement capital that reduces pollution by $\dot{X}$.

Finally, Hartwick makes a further modification to the original optimisation problem (33)-(35), by assuming that the agent's utility is a function not only of consumption, but also of the flow of pollution $\dot{X}$:

(39) $U = U(C, \dot{X})$ *where* $U_c > 0$.

Replacing equation (33) with (39) and (34) with (37), the analytical problem becomes:

$$Max \int_0^\infty e^{-\rho t} U(C, \dot{X}) dt$$

$$s.t. \quad \dot{K} = F(K, L, X) - C - f(b)$$

$$and \quad \dot{X} = \gamma F(K, L, X) - bX$$

Taking the linear approximation of the objective function and substituting from the first-order conditions into the current-value Hamiltonian, Hartwick derives the following expression for the NNP:[11]

$$(40) \qquad \frac{H_c(t)}{U_c} = C + \dot{K} - \left[\frac{U_{\dot{X}}}{U_c} + \frac{f'(b)}{X}\right]\dot{X}$$

Hence, if pollution adversely affects both production and utility, the appropriate correction term is the difference between the price of extra pollution ($\frac{U_{\dot{X}}}{U_C}$) and its marginal cost ($\frac{f'(b)}{X}$). Hence, the usual accounting rule applies also in this case: to obtain a correct measure of NNP, deduct the economic depreciation of the environment in its rental form.

2.3 A more comprehensive approach: the Dasgupta-Kriström-Mäler model and differences in the correction term

As we have seen, Hartwick dealt with the three kinds of natural resource separately and showed that the correction terms that emerge from independent models share the same accounting principle. However, some authors prefer to develop a single model that combines all kinds of natural resources simultaneously to get a corrected measure of NNP. Among them, a major contribution is that of Dasgupta, Kriström and Mäler, (henceforth DKM, 1997). As we show below, the accounting prescriptions that emerge from DKM differ from those achieved by Hartwick. This can be explained by the different analytical settings of these two papers. Different models obviously lead to different magnitudes to be netted out. In fact, as we pointed out above, the formula of the correction term depends on the expression of the current-value Hamiltonian, which in turn is determined by the features of the optimisation problem, namely, the arguments of the utility function and the constraints to the maximisation.[12]

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[11] Note that it follows from the first order conditions that the term in brackets is positive.

[12] As Hartwick (1990, p. 303) states: “Imbedded in this (current-value) Hamiltonian were the formulas for netting-out the ‘consumption’ of natural resource stocks over the accounting period”.

The first major difference between Hartwick and DKM lies in the objective function. In DKM the agent's utility is not only a function of consumption C of the good produced by the economy, but also of leisure l and the environment. The latter enters the utility function in three different forms:

1) the consumption E of a renewable resource (e.g. fuelwood from forests which can be used to cook)
2) the stock K_2 of an environmental capital good (e.g. clean air)
3) the flow A of environmental amenities.[13]

The objective function in DKM is thus:

$$(41) \quad \int_0^{\infty} e^{-\rho t} U(C,l,E,K_2,A)dt$$

where utility increases in all its arguments. Call O the vector of the arguments of the utility function: O = $[C,l,E,K_2,A]$.

As mentioned above, a second difference between Hartwick and DKM is that the latter deal with all forms of natural capital simultaneously. We thus have four different kinds of capital stock in the model:

1) the stock of man-made capital K_1
2) that of environmental capital K_2
3) the stock of the renewable resource K_3
4) that of defensive capital K_4

A different kind of labour Lj (j = 1…4) is associated with each form of capital.

Pollution P reduces the environmental amenities A and the stock of environmental capital K_2 (e.g. clean air or water). However, society can intervene to counter the effects of pollution in two ways:

1) it can make defensive expenditures R to restore environmental amenities damaged by pollution
2) it can invest in defensive capital K_4 that reduces the level of pollution.

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[13] Note that only the first form (consumption of renewable resources) is present in the utility function assumed by Hartwick. Moreover, the fact that leisure is among the arguments of the objective function implies that labour is now a choice variable in the model.

We then have that pollution increases with production, but decreases with defensive capital:

(42) $P = P(Y,K_4)$ where $P_Y>0$, $P_{K4}<0$ and $Y = F(K_1,L_1)$

whereas the environmental amenities A decrease with pollution and increase with defensive expenditures:

(43) $A = A(P,R)$ where $A_P<0$, $A_R>0$

Substituting (42) into (43), we get:

(44) $A = A[P(F(K_1,L_1),K_4) ; R]$

Notice that, unlike Hartwick, DKM introduce a twofold defensive intervention (R and K_4) in their model. This intervention affects the agents' utility in two ways. First, R and K_4 influence the level of environmental amenities A via equation (44), which in turn affects the agents' well-being via equation (41). Second, expenditures in R and K_4 reduce consumption (and thus the utility level) since:

$$C = F(K_1, L_1) - \dot{K}_1 - \dot{K}_4 - R$$

The optimal trajectory of the economy in DKM is determined by maximising (41) subject to (44) and the equations of motion of the capital stocks. In this case, the corresponding current-value Hamiltonian is:

(45) $$H_C = U(C, l, E, K_2, A) + p\dot{K}_1 + q\dot{K}_2 + r\dot{K}_3 + s\dot{K}_4 + vA(P(F(K_1, L_1), K_4), R)$$

where p, q, r, s and v are the costate variables associated with the constraints.

As the authors show, the above Hamiltonian satisfies the following important condition:

(46) $$\int_t^{\infty} e^{-\rho(s-t)} U*(\bullet) ds = \int_t^{\infty} e^{-\rho(s-t)} H_c * ds$$

where $U*(\bullet) = U(C^*, L^*, E^*, K_2^*, A^*)$

The above equality states that the current-value Hamiltonian expresses a utility level which, if maintained constant from t to infinity, would have the same present discounted value of utility along an optimal path from t onwards. As Heal (1998) has underlined, this result is very general and does not depend on the model we are analysing.[14] This is

[14] In fact, Heal (1998) shows that this equality holds true in any problem of optimal dynamic use of natural resources.

confirmed by comparing equations (46) and (4): the former is just a reformulation of the latter with the optimal value of Weitzman's linear utility function (C*) on the left-hand side replaced by that of a general utility function (U*). We can therefore reformulate Weitzman's conclusion and claim that the NNP is *the stationary equivalent of the future utility stream*.[15] Hence, as Heal (1998, p.167) states, "the (current-value) Hamiltonian is a measure of the *sustainable utility level* associated with an optimal path" and it is therefore a measure of welfare.

However, Heal (1998, p. 167) also points out that "the absolute value of the Hamiltonian has no significance". In fact, when implementing a specific policy, what matters is the effect that the policy has on the sustainable utility level (and thus on social welfare) rather than the level itself. Therefore, what we should examine is "whether the policy increases the value of a linear approximation to the Hamiltonian" (Heal 1998, p.167).

This is exactly what DKM do. In order to evaluate the effect of a small perturbation (i.e. a project that leaves prices unchanged), they take the first order Taylor approximation of the current-value Hamiltonian around the vector of optimal values O*:

$$(47) \qquad LH_c = H_c(O^*) + \left.\frac{dH_c(O)}{dO}\right|_{O=O^*} (O - O^*)$$

where LH_c is the linearised current-value Hamiltonian.

Omitting the constant (which does not affect the outcome of the maximisation), DKM take the term $\left[O \left.\frac{dH_c(O)}{dO}\right|_{O=O^*} \right]$ as the correct measure of NNP. After a few mathematical manipulations, this term can be written as:

$$(48) \quad NNP = U_C C + p\dot{K}_1 + \underbrace{r\dot{K}_3}_{1} + \underbrace{U_X X}_{2} + \underbrace{q\dot{K}_2}_{3} + \underbrace{U_L \left(\sum_{i=1}^{3} L_i \right)}_{4} + \underbrace{s\dot{K}_4}_{5} + \underbrace{U_A A}_{6}$$

where X is the flow of renewable resources (e.g. the output of fuelwood).[16]

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[15] Recall that in Weitzman the NNP is "the stationary equivalent of future consumption" (see page 4).

[16] As in Hartwick (1990), to obtain the NNP in monetary terms it is sufficient to divide the right-hand side of equation (48) by the marginal utility of consumption U_c.

This result raises two important considerations. In the first place, as pointed out above, DKM (1997) as well as Heal (1998) call NNP *the linearisation of the whole current-value Hamiltonian*. This contrasts with the approach in most of the literature which, following Hartwick (1990), defines NNP as *the current-value Hamiltonian obtained by replacing only the utility function with its linear approximation*.[17] Therefore, all authors resort to some kind of linearisation, since NNP is a linear index. However, different authors linearise different functions and this might lead to diverse conclusions as to the term to be netted-out. This implies that all authors agree on the fact that the current-value Hamiltonian is a measure of sustainable utility (as suggested by equation (46)), but not on how to compute the NNP. In the second place, the correction term suggested by DKM goes beyond that of Hartwick. According to equation (48), the correct measure of NNP is the traditional NNP (consumption plus investments) plus

a) the appreciation (minus the depreciation) of renewable resources ($r\dot{K}_3$)

b) the value of the flow of renewable resources as measured at its shadow price ($U_X X$)

c) the appreciation (minus the depreciation) of environmental capital ($q\dot{K}_2$)

d) the shadow wage bill ($(U_{L_i})\sum_{i=1}^{3} L_i$)

e) the value of changes in defensive capital ($s\dot{K}_4$)

f) the value of changes in the flow of environmental amenities ($U_A A$)

Like in Hartwick, every component of the corrected NNP is valued at its shadow price. Moreover, there is a one-to-one relationship between some terms in (48) and those determined by Hartwick. In fact, terms a) + b) above correspond to the correction measure $\frac{U_E}{U_c}E + [\frac{U_E}{Uc} - f_E]\dot{Z}$ in equation (30) computed by Hartwick for the case of

[17] Had we linearised only the utility function rather than the whole Hamiltonian, the NNP in DKM would be (omitting the constants):

$$NNP = U_C C - U_l(\sum_{i=1}^{4} L_i) + U_E E + U_A A + U_{K_2} K_2 + p\dot{K}_1 + q\dot{K}_2 + r\dot{K}_3 + s\dot{K}_4 + vA[P(F(K_1, L_1), K_4), R]$$

renewable resources. Similarly, term c) above corresponds to $\left[\frac{\rho - F_K}{\gamma F_K}\right]\dot{X}$ in equation (36), that is, Hartwick's correction factor for the case of environmental capital.[18]

However, equation (48) embraces some additional terms (d, e and f) with respect to the correct measure of NNP derived by Hartwick.

The presence of term (d) in equation (48) indicates that labour income should not be included in a welfare measure. Mäler (1995) provides an intuitive explanation for this unexpected result. Since agents can choose their optimal allocation of time between labour and leisure, in equilibrium they are indifferent to one more hour of leisure or work. Thus in equilibrium, "the gains from increased production of consumer goods are completely offset by the costs from reductions in leisure" (Mäler 1995, p.140). This result hinges on the obviously unrealistic assumption of perfect-clearing labour markets. However, Mäler argues that the same holds true even if we relax this assumption, provided we take the agent's marginal reservation wage as the accounting price for labour. In fact, if the reservation wage is zero, the shadow wage bill will also be zero, which again leads to the exclusion of labour income from the national product.[19]

According to DKM the investments in the stock of defensive capital (term 5 in equation (48)) should also be included in the national income to arrive at a correct measure of welfare. It is worth pointing out, however, that expenditures R to restore environmental amenities damaged by pollution are not in (48). Therefore, as Mäler (1991, p.6) argues, current defensive expenditures should not be deducted from the NNP to get a "true" welfare measure.[20]

Finally, the flow of environmental amenities (term f in equation (48)) should also be evaluated in the NNP. This is an additional term with respect to the NNP computed by

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[18] Note that K_2 in equation (48) and X in (36) can be thought of as being opposites: K_2 represents the stock of clean air, whereas X is the stock of pollution.

[19]Assuming a zero reservation wage implies that the worker is willing to accept a job as long as she receives any positive wage. This again may be a rather strong assumption. For instance, an agent will probably **not** accept a job if the wage is below the cost of going to work or paying a baby-sitter to look after the children. Therefore, if our interpretation of Mäler's argument is correct, one might still want to include labour income in a measure of national product. However, we will not discuss here this interesting argument proposed by Mäler, as it is beyond the scope of the present paper.

[20] We will return to this point in the next section, where the issue of defensive expenditures will be examined more closely.

Hartwick, who did not include environmental beauty in the agents' utility function. However, natural resources are not only an input in the production function, but also a source of direct well-being (think, for instance, of the pleasure that derives from observing a beautiful natural landscape). Therefore, any loss in environmental amenities should imply a reduction in the welfare measure.

So far we have considered how GNP should be adjusted to take economic depreciation of natural resources into account. In all cases, the adjustment term is computed using shadow values for all changes in capital stock, assuming that the economy moves along an optimal path. However, real economies are characterised by failures in property rights that make them diverge from the production possibility frontier. How can we determine the correction term when observed prices differ from true scarcity prices? Can we still rely on the current-value Hamiltonian as a useful benchmark to determine the adjustment term and thus the corrected NNP?

We will address these questions in the next section where we examine the difficulties that arise in practice when one tries to implement the theoretical arguments seen above to compute a true welfare measure.

3. The problem of accounting prices

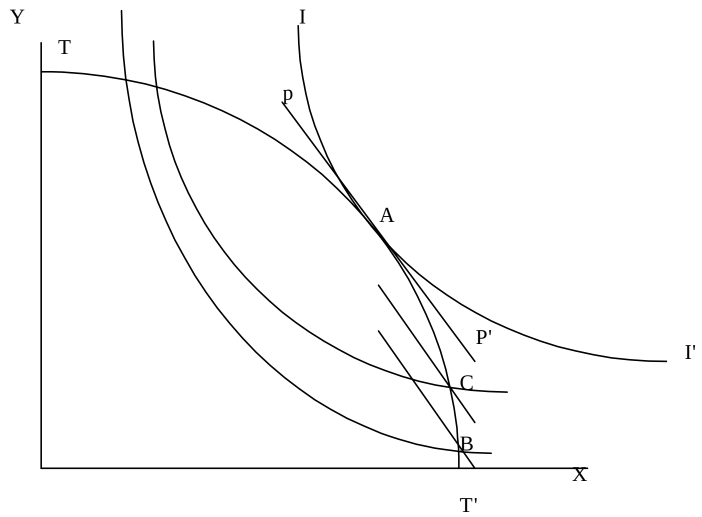
The linearised version of the current-value Hamiltonian is, in fact, a linear combination of values, i.e. prices times quantities, like the national accounting NNP, but unlike the latter, it may be a measure of social welfare. If we could modify the existing accounting version of NNP to take the adjustments suggested by the theory into account we could have a measure of social welfare and we could compare levels of welfare in different periods of time.

The problem with the implementation of the ideal welfare index is that the national accountant uses observed prices and quantities that are generally distorted or non-scarcity prices, whereas the ideal index of welfare is based on accounting prices**.** These can be estimated in a number of ways. One way is to use prices that sustain an optimal plan, i.e.

shadow or scarcity prices. A second is to use “local” prices. DKM (p. 130) explain the problem with some simple diagrams.

Suppose we have an economy consisting of two consumer goods and one individual. Let us assume that X and Y in figure 2 are the consumption goods and TT’ is the production possibility frontier. The individual’s well-being is given by the utility function U(X, Y) and II’ is the individual’s indifference curve which is tangent to TT’. The slope of the common tangent at point A defines the optimal prices p_x, p_y. Thus, at any production point we can define NNP= $p_xX + p_yY$. This is NNP computed using optimal prices. Let us now assume that the economy is at B (a point on the production frontier). We want whether or not a move from B to C is an improvement in the individual’s well-being. Since the bundle C is on a higher indifference curve, C is preferred to B and the utility (welfare) associated with C must be higher than the utility associated with B. Thus, the use of optimal prices to evaluate bundle B and C results in the NNP (as a measure of welfare) at C being higher than the NNP at B.

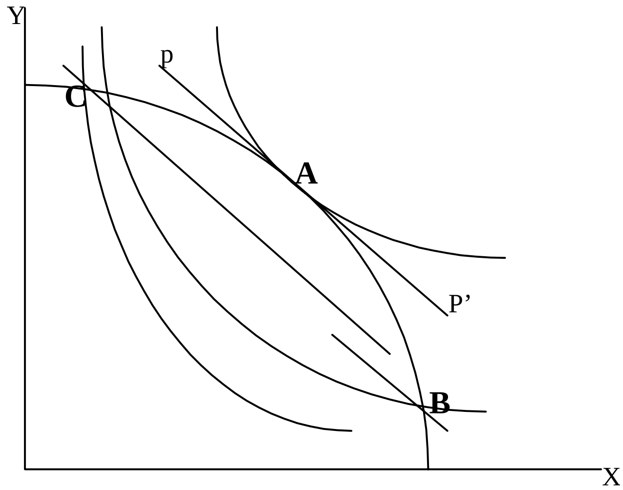
Figure 2: NNP with optimal prices



Source: Dasgupta-Mäler, 1997

However this result depends heavily on the assumption that a shift from B to C is small and along the frontier. Suppose that the project actually causes a large move along the frontier, as in the figure below. In this case the NNP increases from B to C (because we are on a higher budget line for the same prices), but the agent's utility decreases. The same considerations apply if we use local prices to evaluate a big move along the production possibility frontier.

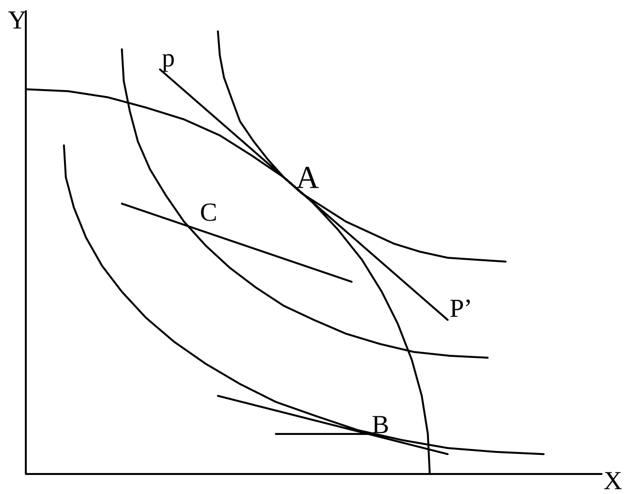
Figure 2a: higher NNP but lower utility level



Let us now suppose that we are not on the production possibility frontier, but on a point in the production possibility set (like point B in Figure 3) as it often occurs in real economies. In this case, optimal prices are inappropriate, because the tangent condition is not satisfied. We can use local prices, i.e. the individual marginal rate of substitution at that point. Suppose that (X, Y) is the bundle chosen by the individual. Suppose that there is a small change in consumption or production: ΔX and ΔY in discrete terms. Since this is a small project, relative prices do not change and the resulting change in the individual's well-being is $U_X \Delta X + U_y \Delta Y$, where $U_x = MU_x$ and $U_Y = MU_Y$[21].

This chang involves an increase in well-being for $(U_X \Delta X + U_y \Delta Y) > 0$ and a decrease for $(U_X \Delta X + U_y \Delta Y) < 0$. Thus, the marginal evaluations of the individual can be used as accounting prices. In other words, NNP evaluated on the basis of current marginal valuation is an appropriate measure of social well-being.

Figure 3: NNP with local prices



Source: Mäler, 1995

In Figure 3, the individual's marginal rate of substitution at B: $-(MU_x/MU_Y)$ is used as "local" prices to evaluate NNP at C. Since C lies on a higher indifference curve, $NNP_C > NNP_B$[22].

Unfortunately the national accountant does not find himself in A position to use optimal prices or "local prices". He uses current prices, i.e. observed prices, that may be distorted or non scarcity prices. This means that if p_x and p_y are current observed prices, they may be different at B and C, so that we do not get an appropriate measure of the variation in social well-being.

The dilemma is that the ideal NNP is very difficult to calculate and true economic welfare can only be associated with these ideal entities, whereas NNP based on observed prices is relatively straightforward to calculate, but cannot claim to be the basis of a welfare measure.

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[21] MU_x being the marginal utility of X in discrete terms: $\Delta U/\Delta X$.

[22] As is the case of optimal prices, this conclusion depends upon the form of the indifference curve.

What we can do is to use the observed prices and quantities, where they exist, assuming that the optimal or local prices are not too remote from the observed prices. With them we try to estimate optimal or local prices for those variables entering the ideal measure of social well-being that do not have an observed market price, such as environmental damages or benefits. This procedure would not however add much rigour to our measurement exercise when all other adjustments are estimated at current prices.

4. Accounting for theoretical adjustments to NNP

4.1 The accounting treatment of defensive expenditures

As derived in section 2 NNP does not include adjustments for defensive environmental expenditures, implying that, if they are part of NNP, they should not be subtracted. However it is often claimed that defensive environmental expenditures should be deducted from an adjusted measure of NNP. What then, is the correct approach? To anwer this question we first need to clarify what defensive expenditures are.

A rigorous definition of defensive expenditures does not exists. Some authors have made an attempt to identify and distinguish them from other forms of expenditures.

Expenditure is said to have a defensive nature when it is related to a negative externality that follows production or consumption activities (as expressed by Hueting, 1980 and Olson 1977), i.e. when it aims at avoiding, reducing or compensating damages caused by an external effect. More specifically, environmental defensive expenditures are (Hueting, 1980) related to environmental externalities, i.e. to loss of environmental quality. The following give an indication of the scope and content of environment-related defensive activities (associated with the corresponding expenditures) as perceived by some authors (Leipert, 1986; Klaus, 1989):

a) Environmental Preventive Measures:
   i) changes in the characteristics of goods and services, changes in consumption patterns;
   ii) changes in production techniques;
   iii) treatment or disposal of residuals in separate environmental protection activities;

iv) recycling;
v) prevention of degradation of landscape and ecosystems;

a) Environmental restoration:
   i) reduction or neutralisation of residuals;
   ii) changes in spatial distribution of residuals, support of environmental assimilation;
   iii) restoration of ecosystems, landscape and so on;

a) Avoidance of damages from repercussions of environmental deterioration:
   i) evasion activities;
   ii) screening activities;

a) Treatment of damages caused by environmental repercussions:
   i) repairs of buildings, production facilities, historical monuments and so on;
   ii) additional cleaning activities;
   iii) additional health services;
   iv) other compensatory activities.

At the accounting level, when categories of activities have been identified it is necessary to produce a disaggregation of flow and asset accounts to identify the monetary data connected with environmental protection activities by economic subject.

The theoretical treatment of defensive expenditures varies according to the economic subject who bears them (we can distinguish between firms' environmental expenditures and environmental expenditures borne by households or the public sector) and to the fact that they may be "current" defensive expenditures or "defensive capital", i.e. when firms accumulate man-made capital that has an environmental defensive function.

In the models of welfare accounting, defensive expenditures enter the social welfare function through the pollution function and thus their impact on the level of social well-being depends on the way the pollution function enters the model. We should distinguish the case where there exists a flow of pollution that is an argument of the production function, as in Hartwick (1990) or in Beltratti (1995) for instance, and the case where pollution does not enter the production function, but has an impact on the social welfare function through one of the other determinants of welfare, such as environmental quality or environmental amenities, as in DKM (1997).

It is often argued that defensive expenditures borne by firms are intermediate in nature and are therefore not part of the Value Added (VA) or NNP. This argument is not correct because they are included in the VA of selling companies and thus contribute to NNP like any other intermediate good. Are there any other arguments in favour of their deduction?

To answer this question, let us again consider two of the theoretical models on welfare accounting and the environment: Hartwick (1990) and DKM (1997) and their treatment of environmental variables.

Hartwick considers the environment from a capital-theoretical perspective and tries to express changes in environmental capital stocks as "economic rents" as for any other capital good. Hartwick considered a stock of environmental pollution (section 2.2.3 equation (31)), as a negative input in the production function of firms:

$$Y = F\left(\underset{+}{K}, \underset{+}{L}, \underset{-}{X}\right)$$

We can think of X as being negatively correlated with a stock of environmental capital $S_1 = S_0 - X$ where S_0 is the initial stock of environmental capital. Thus we can write Hartwick's production function as $Y = \left(\underset{+}{K}, \underset{+}{L}, \underset{+}{S_1}\right)$. As we saw from equation (32), the flow of pollution is expressed as the change in time of the pollution stock which depends on the level of production[23]:

$$\dot{X} = \gamma F\left(K, L, X\right)$$

Thus production is is decreasing in the pollution stock and the flow of pollution over time is increasing in the level of production[24]. In Hartwick the value of the change in the pollution stock represents depreciation of environmental capital evaluated in dollar terms as explained in section 2.2.3. $\dot{X} > 0$ implies degradation of environmental capital. Since pollution can only be controlle indirectly through the production decision (greater production implies an increase in X and thus a decrease in Y), the depreciation of environmental capital is expressed as missed investment in reproducible capital K due to

[23] We ignore the rate of natural regeneration of the environmental stock for the sake of simplicity.

decreased production. When firms invest in abatement technologies, they neglect investment in reproducible capital K in favour of pollution abatement capital, the value of which represents depreciation of environmental capital. Thus, in this model the value of “defensive capital” (defensive expenditures in the capital account) approximates the value of the change in the stock of pollution X. Capital defensive expenditures should therefore be accounted for in the measure of aggregate welfare, because they represent the value of depreciation of environmental capital.

As to current defensive expenditures borne by households and the public sector, in the Hartwick model we do not have a flow of current defensive expenditures that enters the social welfare function directly or indirectly. This is because current defensive expenditures are usually introduced in the model as an argument of an “environmental quality” or “environmental amenities” function that is absent from the Hartwick model. He simply assumes that changes in the pollution stock, $\dot{X}$, enter the utility function directly.

As we saw in section 2.2, by treating the environment as a capital variable, Hartwick obtains four kinds of environmental adjustments to NNP, all expressed as “economic rents”, i.e. market price minus marginal cost. The welfare measure resulting from the Hartwick model is thus given by:

NNP+

a) net depreciation (or appreciation) of exhaustible resources;
b) net depreciation (or appreciation) of renewable resources;
c) net depreciation of environmental capital expressed by the capital defensive expenditures;
d) environmental damages or benefits resulting from changes in the pollution stock that enter the utility function directly.

In the Hartwick model there is no explicit treatment of current defensive expenditures. What we only can infer that capital defensive expenditures by firms should

[24] This is reasonable: as Beltratti (1995, p.3) has pointed out: “firms emit in order to produce and suffer themselves from pollution; this happens in very polluted areas such as Mexico City where there is evidence of decreased productivity of workers as a consequence of bad environmental conditions.”

be considered in a welfare measure as an approximation of the value of the change in environmental capital over time.

A more general treatment of the environment that also includes current environmental defensive expenditures is found in the DKM model as explained in section 2.3. Here renewable resources are modeled as a stock variable $K_{3.}$ Moreover there is a stock of environmental capital K_2, such as clean air or water, that does not enter the production function, as can been seen from equation (42). Instead, K_2 enters the aggregate welfare function directly and its variations are considered as depreciation of environmental capital.

There is also a flow of pollution P which increases with the level of production Y, as in Hartwick, and decreases with the stock of defensive capital, K_4, which is here included explicitly in the model, as shown in equation (42). Current environmental defensive expenditures enter the model through a flow of environmental amenities (otherwise called “environmental quality”) which is increases with R, the flow of current defensive expenditures, and decreases with P as shown in equation (43). Environmental amenities, A, enter directly the aggregate welfare function in the following way:

$$U\left\{\underset{+}{A}\left[\underset{-}{P}\left(\underset{-}{K_4},\underset{+}{Y}\right),\underset{+}{R}\right]\right\}$$

In this model we therefore have a stock of defensive capital that has an indirect impact on welfare, as in Hartwick, and a flow of current defensive expenditures, R, which also has an indirect impact on welfare through the flow of environmental amenities.

In both models there is the problem of how to evaluate environmental benefits or damages arising from changes in $\dot{X}$ (in Hartwick) or A (in DKM) that must be included in the correct welfare measure. The difference between the two models is that DKM introduce current defensive expenditures through the flow of environmental amenities A, whereas Hartwick does not. Since R are included in the final demand (and are thus already part of NNP), there is no need for an additional treatment of current defensive expenditures when the value of changes in A is accounted for. The correct measure of welfare according to the DKM model is thus given by the terms a to f described in section 2.3. When the term ,f, the value of changes in the flow of environmental amenities, is computed, current defensive expenditures, that are already included in the final demand, should not be deducted.

From the above analysis we can draw some conclusions about the treatment of defensive expenditures in national accounts.

A) Current defensive expenditures by firms are intermediate inputs into the production function and, as such, they are only part of the VA of firms that produce them.

B) When capital defensive expenditures borne by firms are used to reduce pollution they can be taken as an approximation of the depreciation of environmental capital. In these cases capital defensive expenditures do not enter the aggregate utility function directly, but through the production function.

C) When current household defensive expenditures are an argument of the flow of environmental amenities or environmental quality (as in DKM), their welfare effects are reflected in the variation in the flow of environmental amenities and there does not seem to be a need for a separate treatment of current defensive expenditures in national accounts.

A different interpretation of the accounting treatment of household defensive expenditures is given by Hamilton (1996, p.25). He assumes that household defensive expenditures directly affect benefits obtained from the environment which are an argument of the aggregate welfare function, an interpretation similar to DKM. However he reaches a different conclusion as to the accounting treatment of household defensive expenditures. From a purely accounting viewpoint, deducting defensive expenditures determines a corresponding increase in the final demand[25], but it also cancels out the part of environmental amenities or services linked to household defensive expenditures. Thus DKM argue that if the level of environmental services is assumed to be affected by defensive expenditures, they cannot be deducted from NNP when the value of the change in environmental services is included.

From a welfare viewpoint, however, household defensive expenditures do not produce utility per-se, but they produce environmental benefits and their value should

[25] Because the part of income spent on defensive goods is now spent on purely consumption goods.

therefore be deducted from final demand when the value of changes in environmental benefits is included.

4.2 Environmental damage

When the flow of pollution or environmental quality has a direct impact on the aggregate utility level, there is a need to account for changes in utility due to changes in the level of pollution or in the level of environmental quality. This raises the problem of how to estimate environmental damage or benefits.

Again one should distinguish between firms and other economic agents. Indeed, as far as the damage harms companies, it is already included in conventional accounts via variations in production. There is therefore no need to explicitly include current reduction to the production level caused by environmental damage. On the other hand, damage to households which decrease utility and thus welfare are not included in the accounts and it is therefore necessary to obtain data on environmental damage.

Over the last thirty years, different techniques for doing this have been developed, such as the contingent valuation method. These techniques have the important advantage of expressing the value of environmental costs or benefits in “local” prices, i.e. in terms of marginal willingness to pay or to accept a variation in environmental quality. As mentioned above, “local” prices are a correct way of measuring variations in social well-being which is a good reason for trying to estimate them.. However, these methodologies are sophisticated and usually damage-specific, i.e. they can only be applied to specific examples of environmental damage (or benefits). The possibility of using them to evaluate all damage on an aggregate basis is remote and the cost would probably be prohibitive. Less precise but robust techniques are therefore needed to evaluate environmental damage on an aggregate scale.

One possibility is to use defensive expenditures as an approximation of environmental damage and subtract them from the accounts. There is, however, no rigorous foundation in the procedure of approximating environmental damage through the level of defensive expenditures. To the contrary, we can think of examples where defensive expenditures are not proportional to damage[26].

An alternative, proposed by Mäler (1997), is to treat environmental damage in the same way as production by the public sector is treated in national accounts. Also in this case we have production of goods and services that are not valued in the market. National accountants have solved the problem by looking at the cost of production in the public sector, mainly the cost of labour. Using the same idea to estimate the value of environmental damage requires politically determined targets for environmental quality and the assumption that these targets reflect social preferences as regards environmental quality. In this case, the cost of reaching the politically determined standard for environmental quality would be an approximation of environmental damage. The situation is represented in figure 4 (from Mäler (1995)). Let us assume that MAC is the marginal abatement cost of polluting emissions and MEC is the marginal external cost or marginal damage from emissions. The total abatement and external cost is minimised when the marginal abatement cost equals the marginal damage cost, i.e. at point E. If current emissions are at D, it is desirable to reduce emissions' to C. The total cost of doing so is given by the area CDEA, and the reduction in environmental damage from emission reduction by the area ECDB.

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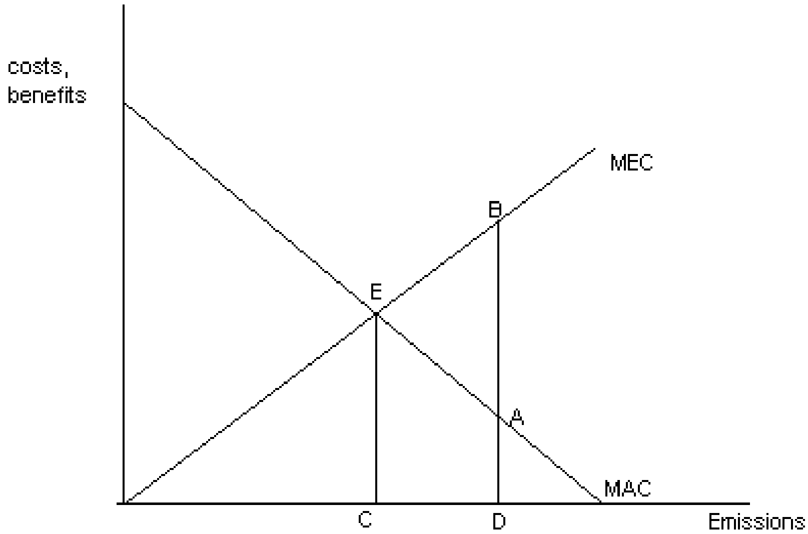
26 Let us consider of an oil spill in the ocean. The cleaning and restoration cost of the oil spill is easy to quantify and possibly limited in amount, whereas the environmental damage is presumably much greater.

Figure 4: Environmental Damages and Abatement Costs



Source: Mäler, 1995

The two areas are correlated because an increase in total environmental damage due to an increase in emissions is accompanied by an increase in the total abatement cost of achieving the optimum level of emissions. Thus, the cost of achieving the target reduction of emissions is a rough approximation of the environmental damage.

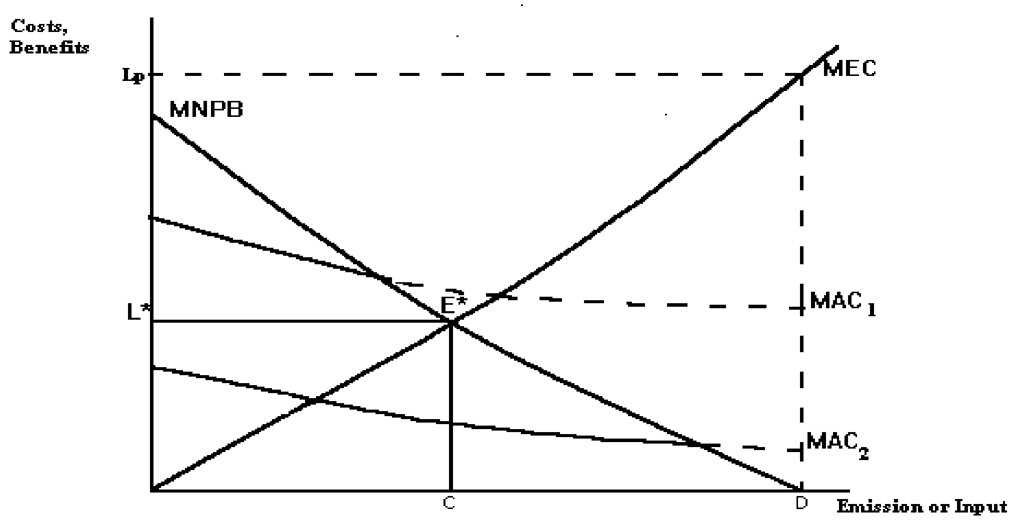
This approach relies heavily on a few assumptions: a) that politically determined targets for environmental quality exist; b) that politically determined targets are the only expression of true social preferences we have; c) that the marginal damage curve is linear. Unfortunately a) is seldom true: in the European Union, for instance, only a few areas are regulated in this way; c) is a simplification: if the MEC is a logistic or exponential function, abatement costs of emissions may be a very poor approximation of damage.

Oskam (1993) proposed a related approach for the Netherlands. Suppose we are trying to estimate the level of marginal environmental cost[27] of a negative external effect caused by emissions from polluting factors of production (like chemical fertilisers and pesticides). Figure 5 (from Oskam), shows a MEC curve, assumed to be linear and increasing with increasing emissions. Two other curves are drawn: the Marginal Net

[27] In this section, we assume that marginal environmental and marginal damage costs coincide, although this is not necessarily the case.

Private Benefits (MNPB) curve and the MAC curve similar to the one in Figure 4. In an equilibrium situation with no charge for external costs, the producer would choose the level of emissions at which marginal private costs equal marginal private benefits, i.e. MNPB=0, because at this point profit is maximised. The MAC curve may be high or low according to the type of external effect in question. For instance, in agriculture where producers are not even aware of their own level of emissions and abatement plants to reduce leakage of chemicals may be extremely costly to implement, MAC are likely to be very high. To represent the fact that the position of the MAC curve depends on the type of pollution, we draw two MAC curves corresponding to high (MAC_1) and low (MAC_2) marginal abatement costs of emissions.

Figure 5 : Marginal external costs (MEC), marginal net private benefits (MNPB) and marginal abatement costs (MAC) of an emission



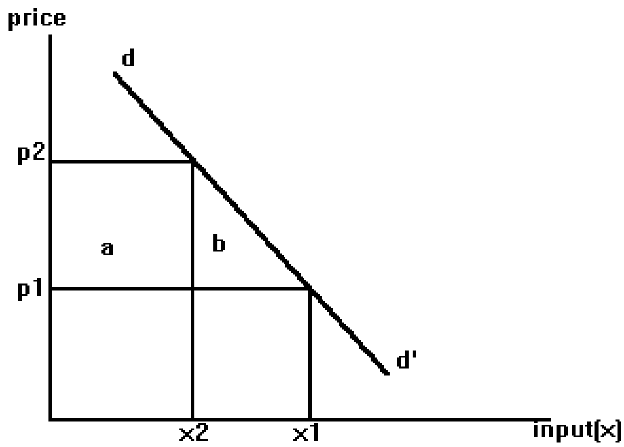
Source: Oskam, 1993

If the most efficient way of reducing emissions is used, the relevant part of MAC is that below the MNPB curve. This is because the producer would not use a quantity of input x for which the abatement cost is higher than the marginal benefit of production. He would rather reduce the amount of input x used. Thus, abatement costs sometimes determine the optimal level of emissions (as assumed, for instance, by Mäler), but under other conditions (when the MAC curve is very high) the MNPB curve is relevant. Unlike the MAC curve, the MNPB curve may be quite easy to estimate, as explained below. When this is so, the optimal level of emissions E* reveals a point on the MNPB and the MEC curves. If we assume that the MEC curve runs through the origin and has a particular form (not necessarily linear), we can generate it.

How can the MNPB and the MEC curves associated with level c of emissions (i.e. L*) be derived? To determine the optimal emission level, c, we can assume consistent decision making by the government in choosing a level of emissions satisfactory from a social point of view. It could be, for instance, the standard level of a polluting input established by the European legislation. The crucial assumption is, of course, that the chosen level of emissions is the sociallt optimal one.

The MNPB curve represents marginal profits to the producer and, under perfect competition, also that part of the demand curve of the polluting input x above the input market price p. Let us focus on this part of the MNPB curve, shown in figure 6.

Figure 6 The demand curve for an input



Source: Oskam, 1993

Here the demand function for input x has a linear representation IN the form:

$$X = \beta_1 + \beta_2 p$$

$$\beta_1 > 0$$

$$\beta_2 < 0$$

In order to induce the producer to reduce the quantity of x from x_1 to x_2 (from D to C in Figure 5) the price must be increased from p_1 to p_2 (L* in Figure 5). Thus, by knowing the demand curve we can estimate the change in the consumer surplus associated with the increase in input price necessary to achieve the desired reduction. This decrease in the consumer surplus (in this case, the consumer is a producer) is given by area b in Figure 6 (which corresponds to area E*CD in Figure 5) and represents the utility loss due to the reduction in consumption of x.

The information about parameters β_1 and β_2, needed to derive the demand curve, is simple to obtain when we know the average price elasticity of demand for input *x* ($\bar{e} = \frac{d\bar{x}}{d\bar{p}} \cdot \frac{\bar{p}}{\bar{x}} = \beta_2 \frac{\bar{p}}{\bar{x}}$) , the average quantity $\bar{x}$ and the average price $\bar{p}$ of the polluting input: $\beta_1 = \bar{x}(1-e)$ and $\beta_2 = e\bar{x} / \bar{p}$. Once the parameters have been estimated, the MEC at E* is given by $\frac{\Delta p}{\Delta x} = \frac{1}{\beta_2}$ and thus $\Delta p = \frac{1}{\beta_2} \Delta x$ where Δp is the MEC associated with x_s and Δ is the reduction of emissions to be achieved in n years.

Once a point on the curve has been estimated we can choose a functional form for the MEC curve and obtain MEC at different levels of emissions.

The two procedures described here are only rough approximations of the level of environmental damage, but they have the important advantage of being quite easy to implement and to apply at an aggregate level. In particular, the demand curve for a polluting input is easier to obtain than the corresponding MAC curve.

4.3 Depreciation of exhaustible resources

The theoretical analysis shows that the value of changes in the natural capital stock should be included in our ideal measure of social well being. More precisely, we should add the product of the accounting price times the change in the resource stock to the conventional accounts. For many of the resources included in the stock of natural capital, the same valuation problems arise as for the flow of environmental benefits or damage discussed above. However, there are also important resources, such as oil, which have market prices. In our optimal planning models depreciation of exhaustible resources is simply the degradation in value of a capital asset under optimal use. Once we have accepted the fact that optimal prices are too difficult to estimate and market prices can be used as an approximation, there are different ways of computing depreciation.

a) The Change in Value Method

Hartwick & Hanemann (1989) have reviewed the approaches to the calculation of exhaustible resource depreciation. Since depreciation is simply the degradation in value of a capital asset under optimal use, it can be computed by calculating the value of the asset, e.g. oil, at the beginning and end of the period and taking the difference, assuming that the resource is being used optimally.

This is called the Change in Value Method. If not available from market data, the value of a pool of oil at any time can be computed by summing the discounted net revenues expected each year for as long as it operates, assuming an optimal schedule of extraction. Let us write the value of an exhaustible resource asset in period t as the sum of the discounted future rents:

(49) $V_t = R_t + 1/(1+r)R_{t+1} + 1/(1+r)^2R_{t+2}+\ldots\ldots\ldots + 1/(1+r)^nR_{t+n}$

where V is the value of the exhaustible resource stock; R is the annual rent; r is the market interest rate and t+n the time at which the resource will be exhausted. If we begin depletion at year t, n is the years of life of the resource remaining to the pool of oil in year t.

Depreciation, the Change in Value, can be written as:

(50) $V_t - V_{t+1} = R_t - r/(1+r)V_{t+1}$

Computing depreciation by the Change in Value Method usually means estimating the value of the exhaustible resource stock at different time periods, determining the size of the deposits, the future schedule of extraction and the price and costs charged for each ton extracted. This difficult task can be avoided by deriving a mathematical equivalent that is easier to compute.

b) The total Hotelling rent

The total Hotelling rent, which is easier to compute, has been found to be equivalent to the above definition of depreciation. The total Hotelling rent is the portion of profits that accrues to extraction firms because they are depleting an exhaustible resource. Hotelling's rule implies that if a resource is exhaustible, it will be depleted more slowly than if it were in infinite supply; the resource owner extracts less than the amount that would equate marginal revenue to marginal cost and, consequently, even a competitive firm earns a rent or profit on the marginal ton equal to the difference between the market price and the marginal cost of extraction. The rent that exists on the marginal ton of an exhaustible resource, the Hotelling rent, is therefore a measure of the intertemporal scarcity of the exhaustible resource. It reflects the fact that the exhaustible deposit is shrinking as it is used. The total Hotelling rent (Hotelling rent multiplied by the total quantity extracted) equals depreciation, as proved in Hartwick & Lindsay (1989).

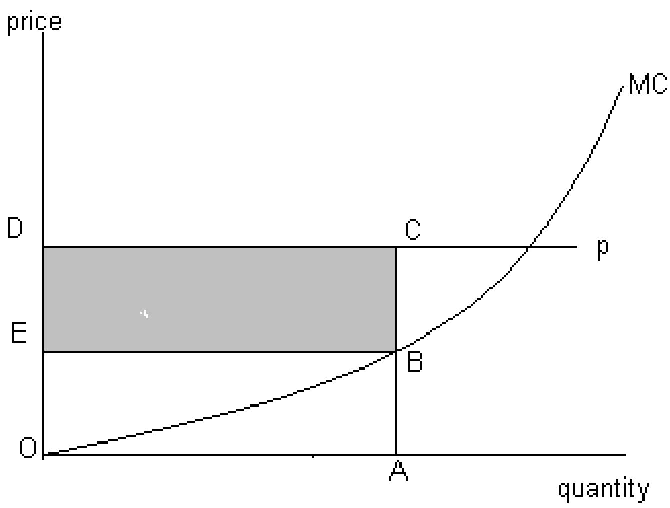
The total Hotelling rent calculation requires much less information that the Change in Value calculation: price (or marginal revenue) and marginal cost to form marginal profits or (Hotelling rent) and the quantity of resource extracted. It is also much easier to compute since it requires no schedule of extraction, no discounting of future receipts and no prediction of future prices or costs.

The main problem in implementing this accounting rule is to obtain marginal extraction costs for the mineral extracted. Usually the problem is solved by using average extraction costs rather than the marginal cost corresponding to the quantity extracted, as in Repetto (1989). However, if the marginal extraction costs curve is increasing, as is usually the case, total extraction costs calculated using average extraction costs are smaller than total extraction costs using marginal costs. In Figure 7, the total extraction cost calculated using the marginal cost at A is given by the area OABE. In this case economic depreciation is given by the area EBCD. This area corresponds to what Hartwick (1990) calls "true economic depreciation" given by the formula $[F_r - f_r]R$.

In terms of Figure 7 this becomes (P – MC)OA = CB*EB, the true economic depreciation. If instead of using marginal extraction costs at A, we use average costs, the total extraction cost is given by the area OAB (under the marginal cost schedule), which is smaller than total extraction costs calculated using marginal extraction costs, and economic depreciation is now given by the area OBCD. As Hartwick has pointed out, it is quite clear that the use of average costs overestimates true economic depreciation: "*…..marginal harvesting costs will be difficult to obtain and substituting average harvesting costs will most plausibly over-estimate true economic depreciation*" (Hartwick 1990, p. 296).

However, when one decides to use marginal extraction costs to calculate true economic depreciation, it can prove difficult to obtain the marginal extraction cost schedule.

Figure 7 Total extraction costs using marginal and average extraction costs



c) The El Serafy method

According to El Serafy (1989) extraction activities are not human production, but the liquidation of an exhaustible resource. Net receipts from an asset should therefore be divided into two components: the first is capital consumption, i.e. receipts earned at the expense of eroding the value of the resource. This is also called "user cost" or economic depreciation. The other component is value-added or true income. El Serafy adopts the Hicksian notion of income, i.e. the level of consumption that can be sustained indefinitely. Earnings or net receipts constitute a finite stream of rentals R, but one could sell the resource stock, valued according to its finite stream of rentals, and place the value V in a bank earning interest X every year from then on. Any finite stream of rentals R earned by the resource stock can thus be equated to an annuity X every year into the future. The difference between R and X is economic depreciation or “user cost”.

(51) $R_t + 1/(1+r)R_{t+1} + 1/(1+r)^2R_{t+2} +\ldots\ldots+ 1/(1+r)^nR_{t+n} = X + 1/(1+r)X + 1/(1+r)^2X +\ldots\ldots 1/(1+r)^nX + 1/(1+r)^{n+1}X +\ldots\ldots$

If we assume, as El Serafy does, that the rental R is constant every year we get:

$\boldsymbol{R_t = R_{t+1}=R_{t+2}=\ldots\ldots=R_{t+n}}$

The finite flow of rentals R earned every year in equal amounts for n+1 years (where n+1 is the last year of resource depletion) is given by the sum of n+1 terms of a geometric progression with reason 1/(1+r) which is equal to:

$$(52)\qquad R(1+r)\sum_{t:1}^{n+1}\frac{1}{(1+r)^t} = R\left[\frac{1-\dfrac{1}{(1+r)^{n+1}}}{1-\dfrac{1}{1+r}}\right] = R\left[\frac{(1+r)^{n+1}-1}{r(1+r)^n}\right]$$

Expression (52) gives the rent from an exhaustible resource calculated as a finite succession of yearly discounted payments, where the first payment is anticipated, i.e. due at the beginning of the first period. Similarly, the infinite flow of a constant annuity X is given by the terms of a geometric progression of reason 1/(1+r) and is equal to:

(53) $X + 1/(1+r)X + 1/(1+r)^2X +\ldots\ldots 1/(1+r)^nX + 1/(1+r)^{n+1}X +\ldots\ldots=$

$$X(1+r)\sum_{t=1}^{\infty}\frac{1}{(1+r)^t} = X\left[\frac{1+r}{r}\right]$$

Setting $R\left[\frac{(1+r)^{n+1}-1}{r(1+r)^n}\right] = X\left[\frac{1+r}{r}\right]$, multiplying by $r(1+r)^n$ and rearranging we obtain economic depreciation or “user cost”:

$$(54)\quad R-X = \left[\frac{1}{(1+r)^{n+1}}\right]$$

Expression (54) is called the El Serafy formula for economic depreciation. The main assumption here is that the yearly receipts from resource extraction are constant, whereas they may in fact change from period to period. In this case the El Serafy formula would be a poor approximation of economic depreciation. Moreover, the accountant still has to guess *n* to compute economic depreciation. El Serafy suggests a procedure that turns the El Serafy formula into the El Serafy method. Here *n* is calculated by dividing the total reserves remaining by this year's extraction, thus assuming that this year's rate of extraction will continue into the future and that the resource will be extracted until it is physically exhausted. Because of these simplifying assumptions, the El Serafy method is simple to use: one only needs to estimate *n*, the interest rate and current receipts to estimate economic depreciation; however, it is based on strong assumptions.

5. Final considerations

In this critical review of the main contributions on welfare indices and environmental accounting, it emerges that although this is topical among environmental economists, national accountants and environmentalists, the literature is often unclear on some key points. With regards to the theoretical questions, all the models discussed in section 2 share the conclusion that the adjusted NNP is a correct measure of social welfare. However, the models differ in analytical setting and in the way NNP is computed. Weitzman (1976) takes a linear utility function and shows that the current-value Hamiltonian resulting from his maximisation problem is the NNP (as a measure of true welfare). Many authors have tried to extend Weitzman's analysis to the environmental context to determine the adjustments that should be made to NNP to account for the depreciation of environmental resources. However, the results obtained by Weitzman hinge heavily on the specific assumptions of his model.

To overcome this problem, most of theoretical models on environmental accounting resort to some kind of linearisation in order to obtain a current-value Hamiltonian that is linear in its arguments and thus equal to NNP. Hartwick (1990), for instance, takes a linear approximation to the utility function, whereas Dasgupta, Kriström and Mäler (1997) take a linear approximation to the entire current-value Hamiltonian. In this way they obtain a linear welfare index that is an adjusted NNP without making restricting assumptions on the form of the utility function. Both Hartwick and Dasgupta et al. find that the NNP should be corrected by deducting changes in the stock of natural resources as measured at their shadow values. However, due to differences in the way the economy is represented and in the functions that they linearise, the correction terms suggested by Dasgupta et al. differ from those suggested by Hartwick, especially with regards to the treatment of defensive expenditures and changes in environmental amenities.

Defensive expenditures should not be deducted from NNP when they are a determinant of environmental quality and environmental quality is a determinant of welfare, because they affect the level of environmental services and the value of changes in the level of environmental services is included in the welfare measure. A different interpretation, however, emerges from other studies, such as Hamilton (1996). He argues that when household defensive expenditures are a determinant of environmental quality (or services), their value should be deducted from final demand (because they do not produce utility directly) and their welfare effects will be accounted for in the value of changes in environmental quality. Capital defensive expenditures can be used as an approximation of the depreciation of environmental quality and deducted from NNP. Environmental damages and benefits are difficult to estimates, but the need to obtain estimates at the aggregate levels suggests the use of methodologies that can only be considered approximations to the correct values.

Different methodologies exist for calculating the depreciation of exhaustible resources,. Here, market prices are available, but the data requirements can be heavy. The most accessible methods, in this regard, seems to be the total Hotelling rent.

Two main problems remain. Changes in NNP reflect changes in social welfare when optimal or “local” prices are used. However, the difficulty of estimating accounting prices for all the adjustments proposed means that very few of these adjustments are actually evaluated at accounting prices. We therefore do not know how reliable really is NNP as a measure of welfare. We have also seen how a big move along the production possibility frontier may lead to a loss of welfare, despite an increase in NNP. This further reduces the reliability of NNP as a measure of welfare in social cost-benefits analysis.

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