National Accounts and Environmental Resources

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Abstract. In the paper, optimal growth theory is used to derive the appropriate definition of the net national product concept, when there are environmental resources and environmental damage to take into account. The basic conclusions are that conventional defined NP should be corrected by deducting environmental damage and adding the value of the net change of all resources.

Key words. National growth theory, national accounting systems.

Introduction

National income accounts as we now know them, came into use in the 40s. At that time, they were constructed with the objective of aiding macroeconomic policy analyses. As the prevailing macroeconomic school at that time was Keynesianism, it was natural that the accounting system was designed to give information on the balance between total supply and total demand, on savings and investment in reproducible capital, and on international relations. This system is still very valuable for that purpose. However, the gross national product measure has been used for many other purposes too, the most usual one as a welfare measure. There have been many criticisms against this use of GNP, the argument being that GNP is a gross concept and should be replaced by net national product NNP. However, even if depreciation is deducted from GNP, the NNP measure may still be a bad measure of welfare and in particular in connection with natural and environmental resources. This note is only concerned with the net national product as a welfare measure in connection with these resources. Moreover, this note is only concerned with a theoretical analysis of an appropriate conceptual framework for measuring aggregate welfare. Very few remarks will be offered on the implementation aspects and it is my view that the system described can hardly be implemented one hundred percent. We will have to continue relying on physical and other special indicators to a large extent in order to judge the performance of the economy with respect to the use of environmental resources. In spite of this, it is hoped that this theoretical inquiry will shed light on the problems with the present accounting system.

There are three main criticisms against the present national accounting framework:

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(i) defensive expenditures, i.e. expenditures for measures individuals undertake in order to reduce the impact of environmental damage, are now included in the final demand but should be deducted,

(ii) neither the value of environmental degradation to households nor to firms are deducted in computing the net national income,

(iii) the change in the value of stocks of environmental resources is not included in the accounts.

We will in this short note discuss these points in a very simple but sufficiently general model. We will find that point (i) is not valid, and that (ii) and (iii) are partly valid.

The Model

Let there be two environmental resources y_1 and y_2. y_1 is a flow resource which is available in each time period in the quantity y_{1o}. We can think of it as clean air or clean water. In each time period it can be used as input in production processes (waste disposal). The amount of use as input is denoted z_1. The remaining amount

$$y_1 = y_{1o} - z_1$$

is then an index of the purity of air or water.

The other resource is a stock resource y_2. Let the resource use be z_2 and assume that the resource has a linear growth function. Thus

$$\frac{\mathrm{d}y_2}{\mathrm{d}t} = m(q_3, l_3)y_2 - z_2.$$

Here we have assumed that the growth of the resource can be affected by management, represented by the use of the produced good q_3 and labour l_3. q_3 can be thought of as input of fertilizers in forestry or agriculture. Dasgupta[1] defines an environmental resource as "resources which are regenerative but potentially exhaustible". Therefore, y_2 is an environmental resource in this sense. It can stand for the stock of standing timber, the population of a certain fish species, but also for the asset of clean water or clean air.

Assume that there is only one good produced and that the production function can be written

$$q = f(l_1, k_l, s_1, z_2, y_1, y_2),$$

where l_1 is the amount of labour employed, k_1 the stock of reproducible capital and s_1 the quantity of residuals generated. This is quite a general formulation, implying that not only the harvesting of the stock resource, z_2, but also the stock itself may affect production. In most cases it would be natural to assume that $\partial f/\partial y_2 = 0$. Furthermore, it is also assumed that the flow of environmental services, y_1, may affect production. The firm can also buy pollution control services from special pollution control firms. Their production function is

$$z_1 = g(s_1, l_2, k_2).$$

Here l_2 and k_2 is the amount of labour employed and the capital stock in the pollution control sector. This implies that only the firm is generating pollutants. However, it would be quite easy to extend the model to include household generation of pollutants.

Assume that the households can improve their environment by "defensive" expenditures, that is by using goods for extra insulation, cleaning etc. Let the household production function be

$$y = \varphi(y_1, q_2, l_4),$$

where q_2 is the input of purchased goods, and l_4 is the input of own labour. One could easily introduce a stock of household capital into this production function, but it would not give any further insights (the inclusion of investments in such a stock in an accounting framework will be touched upon later).

Finally, let the household utility function be

$$u = u(q_1, y, y_2, l_5),$$

where q_1 is the consumption of goods and services, and where l_5 is the free time available for recreation. Obviously we have

$$q = q_1 + q_2 + q_3 + I_1 + I_2,$$

where I_i is the gross investment in sector i. This means that

$$\frac{dk_i}{dt} = I_i - \delta_i k_i, \quad i = 1, 2.$$

Assume that the labour supply is exogenous and equal to $\bar{l}$, that is

$$l_1 + l_2 + l_3 + l_4 + l_5 = l.$$

If r is the rate of interest, a dynamic competitive equilibrium can be represented as the solution to the following intertemporal optimization problem:

$$\text{Max} \int_0^\infty e^{-rt} u(q_1, \varphi(y_1, q_2, l_4), y_2, l_5)\, dt$$

s.t.

$$
\begin{aligned}
&q_1 + q_2 + q_3 + I_1 + I_2 = f(l_1, k_1, s_1, z_2, y_1, y_2)\\
&z_1 = g(s_1, l_2, k_2)\\
&y_1 = y_{1o} - z_1\\
&l_1 + l_2 + l_3 + l_4 + l_5 = \bar{l}\\
&\frac{\mathrm{d}k_i}{\mathrm{d}t} = I_i - \delta_i k_i\\
&\frac{\mathrm{d}y_2}{\mathrm{d}t} = m(q_3, l_3)y_2 - z_2.
\end{aligned}
$$

The current Hamiltonian value for this optimization problem is

$$
\begin{aligned}
H = {} & u(q_1, \varphi(y_1, q_2, l_4), y_2, l_5)\\
& -p(q_1 + q_2 + q_3 + I_1 + I_2 - f(l_1, k_1, s_1, z_2, y_1, y_2))\\
& -v_1(y_1 + z_1 - y_{1o}) + \alpha(z_1 - g(s_1, l_2, k_2))\\
& -w(l_1, + l_2 + l_3 + l_4 + l_5 - \bar{l}) + \mu_1(I_1 - \delta_1 k_1) + \mu_2(I_2 - \delta_2 k_2)\\
& + v_2(m(q_3, l_3)y_2 - z_2).
\end{aligned}
$$

Necessary conditions for an optimum are obtained by maximizing H with respect to $l_1, l_2, l_3, l_4, l_5, s_1, z_1, z_2, q_1, q_2, q_3, I_1, I_2, y_1$.

For future reference, the conditions are (if we assume an interior maximum)

$$
\begin{aligned}
&u'_{q_1} - p = 0; \qquad u'_y\varphi'_{q_2} - p = 0;\\
&u'_y\varphi'_{y_1} + pf'_{y_1} - v_1 = 0; \qquad u'_y\varphi'_{l_4} - w = 0; \qquad u'_{l_5} - w = 0;\\
&p - \mu_1 = 0; \qquad p - \mu_2 = 0; \qquad pf'_{l_1} - w = 0;\\
&\alpha g'_{l_2} - w = 0; \qquad pf'_{s_1} - \alpha g'_{s_1} = 0;\\
&v_1 - \alpha = 0; \qquad v_2 m_{l_3} - w = 0; \qquad v_2 m_{q_3} - p = 0;\\
&pf'_{z_2} - v_2 = 0; \qquad pf'_{y_1} - v_1 = 0.
\end{aligned}
$$

Let $v^c_{y_1} = u'_y\varphi'_{y_1}$, that is, the marginal utility of degradation of the flow resource, and let $v^p_{y_1} = p^f_{s_1}$, that is, the marginal productivity of the flow resource. Then $v_1 = v^c_{y_1} + v^p_{y_1}$. Let $v_{pc} = \alpha g_{s_1}$. Then v_{pc} can be interpreted as the price of pollution control. Finally, let $v^c_2 = u'_{y_2}$ be the household's marginal valuation of the stock resource and $v^p_2 = pf'_{y_2}$ the marginal productivity of the stock resource (as distinct from the input z_2) in production.

The stock prices μ_1, μ_2 and v_2 are determined from the differential equations

$$\frac{d\mu_1}{dt} = -\frac{\partial H}{\partial k_1} + rk_1$$

$$\frac{d\mu_2}{dt} = -\frac{\partial H}{\partial k_2} + rk_2$$

$$\frac{dv_2}{dt} = -\frac{\partial H}{\partial y_2} + ry_2.$$

Note that we can also write

$$u_1(t) = \int_t^\infty e^{-r(\tau - t)} p(\tau) f'_{k_1} \, d\tau, \text{ and}$$

$$\mu_2(t) = \int_t^\infty e^{-r(\tau - t)} v_1(\tau) g'_{k_2} \, d\tau.$$

The prices μ_i can therefore be interpreted as the present value of the future return on a marginal increase in the present capital stock. As we will soon see, v_2 can be interpreted as the present value from a marginal increase in the stock resource.

In the same way we have that

$$v_2(t) = \int_t^\infty e^{-r(\tau - t)} (u'_{y_2} + pf'_{y_2}) \, d\tau.$$

Along the optimal path, the Hamiltonian is

$$H^* = u(q_1, \varphi(y_1, q_2, l_4), y_2, l_4) + \mu_1 \frac{dk_1}{dt} + \mu_2 \frac{dk_2}{dt} + v_2 \frac{dy_2}{dt}.$$

Net National Welfare Measure

The Hamiltonian along the optimal trajectory is the national welfare measure in utility terms we are looking for. The linear support of the Hamiltonian along the optimal path is the exact correspondence to the net national welfare measure NWM. It measures the current utility of consumption (of produced goods and services and environmental services) and the present value of the future utility stream from current stock changes. This follows because the stock prices measure the present value of the future contributions to welfare from a marginal increase in the stocks.

The meaning of the linearization requires some further comment. We take the prices along the optimal trajectory, that is the optimal prices, and evaluate all quantities — output, environmental variables, etc., at those prices. No real economy is on the optimal trajectory and one could perhaps ask why we should bother about optimal prices in this connection. The reason is that if the underlying feasibility set is convex, the optimal prices are the only prices that will yield an estimate of the welfare measure that in all circumstances will indicate a true welfare increase or decrease. Thus, with the convexity assumption, the use of optimal prices will give the correct indication of welfare changes, irrespective of whether the economy is on the optimal trajectory or not. It follows that the prices must in general be accounting prices and not actual market prices. Let X be the vector of arguments in the Hamiltonian (except prices) and let X_t^* be a point at the optimal trajectory at time t. We now consider a small pertubation. The value of the Hamiltonian at this new point is the net welfare measure NWM or

$$\text{NWM} = H(X_t^*) + u_{q_1} q_1 + u_y(\varphi_{y_1} y_1 + \varphi_{q_2} q_2 + \varphi_{l_4} l_4) + u_{y_2} y_2 \\ + u_{l_5} l_5 + \mu_1 \frac{\mathrm{d}k_1}{1\mathrm{d}_t} + \mu_2 \frac{\mathrm{d}k_2}{2\mathrm{d}_t} + v_2 \frac{\mathrm{d}y_2}{2\mathrm{d}t}$$

By using the necessary conditions for an optimal trajectory, this can be written:

$$\text{NWM} = p(q_1 + q_2 + q_3) + \mu_1 \frac{\mathrm{d}k_1}{\mathrm{d}t} + \mu_2 \frac{\mathrm{d}k_2}{\mathrm{d}t} \qquad \text{(conventional NP)}$$

$$-pq_3 - w(l_1 + l_2 + l_3) + v_1^{\varsigma} y_1 + v_2^{\varsigma} y_2 + v_2 \frac{\mathrm{d}y_2}{\mathrm{d}t} \qquad \text{(adjustments)}$$

$$+H(X_t^*).$$

The three first terms correspond to the conventionally measured net national product, in that they include the total output for consumption q_1, the total defensive expenditures in households (and public sector) pq_2, the total input of produced goods in enhancing the growth of the environmental asset and the net investment in the stocks of reproducible real capital. This conventional net national product should then be corrected in various ways:

(a) Wages in the production of goods should not be part of the net national product, the intuitive reason being that on the margin, people are indifferent between taking a job on the labour market or being free and spending the time on recreation or on their own work.

(b) Current defensive expenditures pq_2 should not be deducted from net national income in order to avoid double counting when the value of environmental services $v_{y_1}^{\varsigma}$ is included. If we would have introduced household capital, then household net investments to protect *future* environment should have been included.

(c) The value of input goods used to enhance the stock of environmental assets should be deducted from conventional net national product.

(d) The value of the flow services should be included but valued at households marginal valuation $v^c_{y_1}$. The damage to production should not be deducted from NNP, the reason being that this damage has already been accounted for by pq_1.

(e) The value of the current direct use of the stock resource should be included, but valued by the household's marginal valuation and its value in production should not be included.

(f) The value of the change in the stock (not the change in the value of the stock) should be included. Anticipated capital gains are not parts of national income.

(g) The change in the stock resource should be valued at a price reflecting the future value of the stock, both as a source of inputs to production, z_2, as a direct source of utility to household, and as a source of productivity in production. We have

$$\frac{dv_2}{dt} = (r - m)v_2 - (v^c_2 + v^p_2), \quad \text{and}$$

$$v_2 = pf_{z_2}.$$

This means in particular that

$$v_2(t) = \int_0^\infty e^{-(r - m)(\tau - t)}(v^c_2 + v^p_2)\, d\tau,$$

that is the accounting price on the stock resource is equal to the present value of the future gains from the stock.

(h) There is a constant term $H(X^*_t)$ which is not affecting the value of the perturbation. It reflects the wealth of the society and we will come back to a further discussion of this term later. It is obvious that it will not in any way affect the effects on NWM from present economic activities and we will therefore in the mean time neglect it.

Conclusion (a) may be startling. The intuitive reason is as follows. Assume that individuals are free to choose their labour supply, that the labour market is in equilibrium and that the opportunity cost of working is the vacation time that must be given up. On the margin, no individual would get better from an increase in the labour supply. As national welfare is a linear approximation of the true welfare, it follows that labour income should not be included. This shows the importance of being clear of the use of the accounts. For macroeconomic analysis, labour income is obviously one of the most important variables. If we want a measure of welfare, labour income should not be included (giving the assumptions on a perfect labour market). Thus, there is a need to keep the established accounts for giving a basis of macroeconomic analysis and supplementing them with accounts that take labour and environmental resources into account. Note that we have not included the perhaps most important asset — human capital. If human capital would have been included in the model and if parts of wages are return on human capital, then these parts should be included in the NWM-concept. That part of the wage bill that corresponds to "raw labour" should be subtracted from the value of the total output in order for the NWM to provide a good measure of individual welfare.

In the sequel, we shall, for simplicity disregard the arguments presented above and keep to the established procedures of including wages in NWM.

Social Accounting Matrix

These results can be represented in a social accounting matrix for this simple economy. For simplicity we will neglect the term $H(X_t^*)$. Let $I = I_1 + I_2$ and $q = q_1 + q_2$. Moreover, let $v^c = v_1^c y_1 + v_2^c y_2$ represent the total consumer valuation of the two environmental resources and let $v^p = v_1^p y_1 + v_2^p y_2$ be the corresponding value of the resources in the production (except for the value of the first resource for waste disposal and the value of the second resource as an input). Finally let V_i be the surplus of revenues over wages, pollution control expenditures, depreciation, and implicit environmental costs in sector i and let $V = V_1 + V_2$. V_i can be interpreted as the net return on capital.

A Social Accounting Matrix

	H	L	C	Prod.	Poll. C.	$S{-}I$	Env.
H		wl	V				V_e
L				wl_1	wl_2		wl_4
C				V_1	V_2		
Prod	$p(q_1 + q_2)$					I	pq_3
Poll. C.				$v_{pc} s_1$			
$S{-}I$	S			$\delta_1 k_1$	$\delta_2 k_2$		
Env.	v^c			$v^p + v_2 z_2$	$v_1^p z_1$	$v_2^* \mathrm{d}y_2/\mathrm{d}t$	

Here it has been assumed that there is an environment authority that buys labour and produces goods to enhance the growth of the environmental asset. Now interpret the first column as the total final demand, except capital investments, that is, let the public sector be included. We see that the national welfare measure is given by the sum of the first column. It includes current expenditures on goods and environmental services, $p(q_1 + q_2) + v^c$, plus net savings S. As the row sum is equal to the column sum, it follows that national welfare also equals the value added $wl + V$ and the implicit value of all environmental resources V_e. This implicit value of the environment equals the value of the environment to the households v^c, to the firms v^p as a flow of unspoilt resources and as a stock, to the firms $v_2 z_2$ as an input, to the firms for waste disposal, and the net investment in the stock resource $v_2(\mathrm{d}y_2)/\mathrm{d}t$

less expenditures on enhancing the growth of environmental assets. The net savings S equals net investment in reproducible capital and investment in the environmental asset,

$$S = I - \delta_1 k_1 - \delta_2 k_2 + v_{d2} \frac{dy_2}{dt}.$$

The national welfare measure can now be written

$$\text{NWM} = p(q_1 + q_2) + v^c + I + v_2 \frac{dy_2}{dt} = wl + V + V_e.$$

Apparently, it is quite important to separate the household valuation from the importance of the resources in production. The use of the resources in production is reflected in net national income through profits and outputs, while the household valuation is not included in such a way. The value of stock changes, on the other hand, should include both the direct consumer and the indirect production marginal valuations. Local air pollution is an example of the former resources, as a high ambient concentration this year may mean nothing for the ambient concentrations next year. Regional air pollution may offer an example of the stock resource. Sulfur emissions will be deposited as sulfates and if the deposition is in excess of the "critical load", an accumulation will take place leading to long term damage. In the first example, only the direct damage to the consumers should be included while in the second example, the present value of all future damage due to the excess deposition this year should be included in the accounts.

We could easily extend the accounting framework above to include foreign trade and transboundary environmental effects. It is easily seen that the standard identity between the balance of trade and domestic financial savings will be valid in this extended framework.

Let us return to our national welfare measure concept

$$\text{NWM} = p(q_1 + q_2) + v^c + S.$$

Another way of writing it is

$$\text{NWM} = p(q_1 + q_2) + v_1^c(y_{1o} - z_1) + v_2^c y_2 + S.$$

Now assume that $y_{1o} = 0$ (which simply means that we have chosen a zero point for the scale by which the flow resource is measured) and that $v_2^c = 0$. Let us also forget, without any consequences for the generality of the argument, about the use of goods and labour for enhancing growth in the environmental stock resource. Then we have

$$\text{NWM} = pq - ED + S$$

$$= pq + (I - \delta_1 k_1 - \delta_2 k_2) - ED - \left(-v_2 \frac{dy_2}{dt}\right).$$

where ED is the environmental damage $-v_1^c z_1$. This new measure differs from the conventional net national product definition in that we have deducted the environmental damage ED and the degradation of the stock $(-v_2 \mathrm{d}y_2/\mathrm{d}t)$. Thus, the general conclusion is that the conventional net national income should be adjusted in two ways:

deduct current environmental damage as valued by households,

deduct the value of the degradation of stocks with a price reflecting future value of the stock.

Environmental Damage

How do we estimate the environmental damage (or equivalently the value of the environmental services $v_1^c y_1$)? In spite of remarkable progress in estimating the monetary value of environmental damages during the last ten years, it is clear that we are far from a situation where we can estimate them routinely. In view of that, it has often been suggested that the defensive expenditures are a proxy for the environmental damage. Thus, instead of subtracting the environmental damage, one should subtract the defensive expenditures. However, defensive expenditures in general are very bad estimators of environmental damage. Only if the defensive expenditures are a perfect substitute to the environmental services can this approximation be defended (see, for example, Mäler, 1985). In most cases defensive expenditures will have no relations whatsoever with the true damage cost. Thus, this procedure can hardly be seriously considered.

As a more interesting alternative has been suggested that one should specify environmental targets — maximum ambient concentration of SO_2, minimum dissolved oxygen levels in a stream, minimum recreational possibilities for a community etc. In general it is much easier to estimate the cost of achieving these targets than to estimate the loss from not achieving them. The cost of achieving the targets could then be used as a crude approximation of the true social value. If all marginal willingness to pay curves and all marginal abatement cost curves have the usual curvature, we will by following this procedure obtain estimates that are biased downward. Even if the estimates are biased, there is some satisfaction in that the direction of the bias is uniform. However, the bias may differ substantially from one environmental problem to another.

The decision on the environmental targets is a political one. Political beliefs could also be expressed in marginal valuations. Thus, if the politicians after public discussions could decide on the marginal value of environmental improvements, these marginal values could be used to estimate the environmental damage cost.

Last but not least, the art of estimating damage cost functions is rapidly improving. For many environmental problems, values of damage cost can be found — values that can be used in a satellite system of accounts.

Sustainable Income

We can now adapt Weitzman's analyses (Weitzman, 1976) of the welfare significance of national product. In fact, it is possible to show that NWM as defined above is the maximum consumption that can be allowed if future consumption should be prevented from decreasing. First note that

$$\begin{aligned}\frac{\mathrm{d}H^*}{\mathrm{d}t} &= \frac{\partial H^*}{\partial k_1}\frac{\mathrm{d}k_1}{\mathrm{d}t} + \frac{\partial H^*}{\partial k_2}\frac{\mathrm{d}k_2}{\mathrm{d}t} + \frac{\partial H^*}{\partial y_2}\frac{\mathrm{d}y_2}{\mathrm{d}t} \\ &\quad + \frac{\partial H^*}{\partial \mu_1}\frac{\mathrm{d}\mu_1}{\mathrm{d}t} + \frac{\partial H^*}{\partial \mu_2}\frac{\mathrm{d}\mu_2}{\mathrm{d}t} + \frac{\partial H^*}{\partial v_2}\frac{\mathrm{d}v_2}{\mathrm{d}t} \\ &= r\mu_1\frac{\mathrm{d}k_1}{\mathrm{d}t} + r\mu_2\frac{\mathrm{d}k_2}{\mathrm{d}t} + rv_2\frac{\mathrm{d}y_2}{\mathrm{d}t} = r(H^* - u^*),\end{aligned}$$

where u^* denotes the utility along the optimal path. This is a differential equation in H^* with the solution

$$H^*(t) = r\int_t^{\infty} u^* c^{-r(\tau - t)}\mathrm{d}t.$$

Thus

$$\int_t^{\infty} H^*(t)\ \mathrm{e}^{-r(\tau - t)}\mathrm{d}\tau = \int_t^{\infty} u^*(\tau)\ \mathrm{e}^{-r(\tau - t)}\mathrm{d}\tau.$$

The present value of the constant utility stream H^* is thus equal to the maximum present value of the utility stream. Thus $H^*(t)$ is the maximum current utility that can be sustained forever, that is, H^* (or NWM $= H^*$) is a measure of sustainable income (in utility terms).

Sustainable Development

As we have shown that NWM is a measure of sustainable income, it follows that sustainable development can be defined as such a development in which NWM never decreases. Thus

> Economic development is sustainable if and only if utility is non-decreasing over time.

From the analysis in the section above, it is seen that

$$\frac{\mathrm{d}\,\mathrm{NWM}}{\mathrm{d}t} = r\left(\mu_1\frac{\mathrm{d}k_1}{\mathrm{d}t} + \mu_2\frac{\mathrm{d}k_2}{\mathrm{d}t} + v_2\frac{\mathrm{d}y_2}{\mathrm{d}t}\right).$$

If follows that if we define the total stock of capital as

$$K = \mu_1 k_1 + \mu_2 k_2 + v_2 y_2,$$

development will be sustainable if and only if K is non-decreasing at constant prices. Thus, sustainable development requires that the total stock of capital, defined in a special way (first introduced by Solow (1986)), is non-decreasing. However, there is nothing in the preceding analysis that suggests that a sustainable development defined in this way is feasible. If, for example, $m = 0$, that is if the stock resource is an exhaustible resource, and if the substitution elasticity between this stock resource and capital is less than one, the value of the stock resource relative the other capital prices will be such that K always will be decreasing. This has been analysed in Dasgupta and Heal (1981). In particular, that would mean that the sustainable income is zero. On the other hand, if technical progress is introduced in the model, even in this situation, sustainable development may be feasible.

One particular aspect of this is Hartwick's rule which says that sustainable development is achieved when the competitive rents on exhaustible resources are invested in reproducible capital.[2] It is easily seen that our (or rather Solow's) formulation yields a generalization of Hartwick's rule to the case of renewable resources.

It follows from above that

$$H(X_t^*) = rK_t^*,$$

that is H^* is equal to the total return on all capital at time t. This means that the NWM can be written

$$\mathrm{NWM} = rK^* + p(q_1 + q_2 + q_3) + \mu_1 \frac{\mathrm{d}k_1}{\mathrm{d}t} + \mu_2 \frac{\mathrm{d}k_2}{\mathrm{d}t} \qquad \text{(conventional NP)}$$

$$-pq_3 - w(l_1 + l_2 + l_3) + v_1^c y_1 + v_2^c y_2 + v_2 \frac{\mathrm{d}y_2}{\mathrm{d}t}. \qquad \text{(corrections)}$$

This can reasonably be interpreted as the net national product NP.

Unanticipated Changes

The analysis so far has been based on the assumption that the future is known with full certainty. Assume now that there is no reason to reject the assumption of perfect foresight, but that in time period t' there is a completely unanticipated change in a resource stock or in technology (or in world market prices which can be represented as a change in the production function).[3] From period 0 to t', NWM will develop as above up to t' (although we have to assume that the prices used to compute NWM are Arrow–Debreu prices or shadow prices computed so as to reflect the "value" of goods and services and resources in different states of the world).

In t' there will, however, be a shift in the parameters, and therefore also in the optimal path from t' onwards. Thus, NWM will shift in t', and unanticipated capital gains at t' will be included.

In case there is uncertainty about future resource stocks, technology and prices, it can be shown that (Dasgupta and Heal, 1974; Dasgupta and Stiglitz, 1976) essentially the same thing will happen. The difference is that the discount rate r now also must include a risk premium. Thereby the uncertainty of the future will be taken into account. When an unanticipated change takes place, there will be a change in NNI and the economy will follow a new path till the next unanticipated changes are realized.

Thus, it becomes quite important to identify anticipated changes in prices, stocks and technology from unanticipated changes, as this will affect the way NWM should be computed. This conclusion is strengthened if one considers changes in world market prices for goods produced in our economy. If such changes are correctly anticipated, they can be represented in our model as shifts in the production function, that is as technical progress (although in this case technical progress may be negative). Capital gains arising from these price changes should not be included in NWM. Their importance has already been capitalized in other prices and therefore already been included in the net national income concept. Unanticipated gains, on the other hand, have by their definition not been capitalized and should therefore be included in a correct measure of national welfare measure.

Conclusions

In this paper, an attempt has been made to create an analytical framework for a discussion on how to include environmental resources in national accounting systems. It was found that the conventional Net National Product measure should be adjusted in the following ways:

(i) the flow of environmental damage should be deducted from conventional NNP,

(ii) the value of the net change in the stocks of all assets and not only man made capital should be added to conventional NNP,

(iii) investments in the enhancement of stocks of natural resources should be treated as intermediary products,

(iv) existing wealth, as the return on the total stock of assets in the economy should be added.

With these adjustments, there is no need to deduct defensive expenditures or to make any other similar adjustment.

The Net Welfare Measure, so constructed, can be interpreted as the sustainable income, in the sense that it gives the maximum feasible constant flow of consumption.

Furthermore, this maximum flow can be interpreted as the return on the total wealth in the economy.

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Notes

[1] See Dasgupta (1982), p. 14.
[2] See Hartwick (1977), (1978) and Dixit, Hammond, and Hoel (1980).
[3] The following discussion is based on Dasgupta and Mäler (1990).

References

Ahmad, J. J., E. Lutz, and S. El Sarafy (1989), *Environmental Accounting for Sustainable Development*, World Bank, Washington D.C.

Bartelmus, P. and J. W. van Tongeren (1988), *SNA Framework for Environmental Satellite Accounting — Draft Proposals*, UNSO.

Bartelmus, P. (1988), *Accounting for Sustainable Development*, Working Paper No. 8 Department of International Economic and Social Affairs, United Nations.

Dasgupta, P. (1982), *Control of Resources*, Basil Blackwell, Oxford.

Dasgsupta, P. and G. Heal (1974), 'The Optional Depletion of Exhaustible Resources', *The Review of Economic Studies*, Symposium on the Economics of Exhaustible Resources.

Dasgupta, P. and K.-G. Mäler (1990), Environment and Emerging Development Issues, WIDER.

Dasgupta, P. and G. Heal (1981), *Economic Theory and Exhaustible Resources*, Cambridge University Press.

Dasgupta, P. and J. Stiglitz (1976), Uncertainty and Resource Extraction Under Alternative Institutional Arrangements, IMSSS Technical Report 1979, Stanford University.

Devarajan, S. and R. J. Weiner (1988), *Natural Resource Depletion and National Income Accounts*, unpublished.

Dixit, A., R. Hammond, and M. Hoel (1980), 'On Hartwick's Rule for Regular Maximum Paths of Capital Accumulation and Resource Depletion', *Review of Economic Studies* **45**, 551—6.

Hartwick, J. (1977), 'Intergenerational Equity and the Investing of Rents from Exhaustible Resources', *American Economic Review* **66**, 972—4.

Hartwick, J. (1978), 'Substitution among Exhaustible Resources and Intergenerational Equity', *Review of Economic Studies* **45**, 347—54.

Hartwick, J. (1990), Natural Resources, National Accounting and Economic Depreciation, *Journal of Public Economics*, forthcoming.

Mäler, K.-G. (1974), *Environmental Economics — A Theoretical Inquiry*, The Johns Hopkins University Press.

Mäler, K.-G. (1985), 'Welfare Economics and the Environment', in *Handbook of Natural Resource and Energy Economics*, eds. A. V. Kneese and J. L. Sweeney, North-Holland.

Peskin H. (1989), *Accounting for Natural Resource Depletion and Degradation in Development Countries*, Environment Department Working Paper No. 13, The World Bank.

Repetto, R., W. Magrath, M. Wells, C. Beer, and F. Rossini (1989), *Wasting Assets Natural Resources in the National Income Accounts*, World Resources Institute.

Solow, R. W. (1986), 'On the Intertemporal Allocation of Natural Resources', *Scandinavian Journal of Economics* **88**(1).

Weitzman M. (1976), 'On the Welfare Significance of National Product in a Dynamic Economy', *Quarterly Journal of Economics* **90**.