ON "GREEN NATIONAL PRODUCT": THEORIES AND A COMPARISON AMONG DIFFERENT APPROACHES

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Summary

A theoretically "ideal" measure of green Net National Product (green NNP) is derived by finding the Hamiltonian of a dynamic equation which maximizes the utility of a representative consumer. A "sustainable" model of production is derived by limiting production to a level which keeps the quality and quantity of natural resources intact. It is shown that the "ideal" measure is the sum of the NNP under the sustainable mode and the "net benefits" from deviating from that mode. It is also shown that this ideal measure differs from the conventional NNP in that it includes the total post-defense direct service of the environment to consumers, and excludes the economic

depreciation of environmental quality, the economic depreciation of renewable resources, and consumers' defensive spending (because it is a cost borne by the consumers in order to have access to the post-defense environmental services). It is further shown that while all previously developed concepts of green accounting reviewed in this paper have their merits, the "damaged-adjusted net national income" developed by the London Group is closest to our ideal measure, followed by the ENRAP (Environmental and Natural Resources Accounting Project) approach, and further followed by the SEEA (System of Integrated Environmental and Economic Accounting)'s Environmentally adjusted Domestic Product II or EDPII, to which the London Group's "cost-based net national income" is similar.

1. Introduction

Adjustments of conventional national product measures to reflect changes in the value of environmental assets, popularly known as green accounting, have gained considerable attention in recent years. In the United States, intensive work on environmental accounting began in the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce in 1992. Shortly after the first publication of the U.S. Integrated Environmental and Economic Satellite Accounts (IEESA) in 1994, however, Congress directed the Commerce Department to suspend further work in this area and to obtain an external review of environmental accounting. A panel was then organized by the National Research Council and charged to do the work. The findings of the panel were recently released and published as the report *Nature's Numbers*.

There the panel concludes that "extending the U.S. national income and product accounts to include assets and production activities associated with natural resources and the environment is an important goal; and that developing a set of comprehensive non-market economic accounts is a high priority for the nation." The panel explicitly recommends that the "Congress authorize and fund Bureau of Economic Affairs of the Department of Commerce to recommence its work on developing natural-resource and environmental accounts." Elsewhere the work continued without pause in many countries.

Given the growing importance of green accounting, there are unfortunately still doubts around it both theoretically and empirically. This note attempts to clarify some of concepts concerning the treatment of important variables including defensive spending, direct services of the environment, and depreciation, in the process of constructing the green national product. It will do so by comparing the United Nations' SEEA (System of Integrated Environmental and Economic Accounting) and the Philippine ENRAP (Environmental and Natural Resources Accounting Project) framework (closely associated with Professor Henry Peskin) with a theoretically ideal measure of national product, involving an extension of the work by Kirk Hamilton of the World Bank.

The theoretically ideal measure constructed in this paper uses a dynamic theoretical model based on optimization out into the future. It fits into the neoclassical economic growth tradition, in which produced capital is considered substitutable with natural resources (according to the so-called "weak" or "broad" sustainability criterion). This line of research in the context of national accounting goes back to the 1976 paper of Martin Weitzman, who showed that the present value of future consumption would be maximized by maximizing in each period the "national product" as conventionally defined, if the economy is on the dynamically optimal path *and* all contributing elements to growth are appropriately accounted for. Robert Solow subsequently showed that national product could be conceived of as the interest on total accumulated wealth, followed by Dan Usher who discussed the interpretation of the Hamiltonian in the dynamic optimization specification as the return to wealth, where wealth is defined as the present value of future consumption. John Hartwick and Karl-Goran Mäler both extended Weitzman's model to analyze different aspects of the problem, while Kirk Hamilton synthesized and integrated the analysis in two papers published in the mid 1990s by presenting a series of models that touch upon almost all of the important aspects of concern.

In particular, for our purposes, Hamilton's Models 2 and 5 in his 1996 paper as well as some parts of Model 1 in his 1994 paper will be integrated into one model, which will subsequently be transformed and re-interpreted. The idea is to develop a formulation that is as simple as possible, but powerful enough to address the issues at hand. It will be clear that the model to be presented is enough for the purpose, and possible extensions of the model to include other aspects such as exhaustible resources would be intuitive.

2. The Model

2.1. The Set-Up

In the type of dynamic model widely used in this kind of work, the main components are a technological relationship that describes production possibilities, an objective function that describes the things that provide benefits to members of society (in this case, consumption of material goods and services, denoted C, and the environmental benefits they enjoy, denoted Φ), and a series of constraints on, and relationships between, inputs and resources that act as limits on what can be achieved.

The model presented here is an optimal control model, that solves for optimal values of key variables over (in this case) time. Let us define the following symbols:
U = utility (the instantaneous welfare of the society under consideration)
C = consumption other than consumers' defensive expenditure
K = capital stock (produced assets)
F = production
S = stock of (renewable) resource

R = resource extraction/harvest
f = extraction/harvest cost
X = cumulative amount of pollution emitted
g = net natural growth of resource
B = flow of environmental services
d = dissipation rate of the stock of pollution
e = pollution emissions
a = abatement expenditure by producers
Φ = environmental benefits to households
h = consumers' defensive expenditure
L = available labor
LL = total supply of labor

Thus, the economy has a given technology, transforming inputs (capital, labor and resource flow) into outputs. Specifically, the economy produces according to

(1) $F = F(L, K, R)$ (1)

where $F_L > 0,\ F_K > 0,\ F_R > 0$, and $L \le LL$.

This production process is subject to a series of constraints. For $L \le LL$, the inequality holds if some labor is not available due to environmentally caused harm:

(2) $L = LL - \delta(B_0 - B)$ (2)

where $\delta > 0$ is the effect of harm, proportional to the difference between B_0 and B, both of which will be defined immediately below.

The flow of environmental services—a measure of the services received by the population from the natural environment—is governed by

(3) $B = B_0 - \beta(X - X_0)$ (3)

where B_0 is the level of environmental services that flow from a pristine environment, X (X_0) is the stock (initial stock) of the pollutant, and $\beta > 0$. In turn, the rate of change in X is given by

(4) $\dot{X} = e - d(X)$ (4)

where e is emission, and d is the rate of natural dissipation, a function of X.

The rate of change in the (renewable) resource stock is governed by

(5) $\dot{S} = -R + g$ (5)

The extraction or harvest cost of the resource, represented by f, is a function of R:

(6) $f = f(R)$ (6)

where $f_R > 0$. Emission of pollution is given by

(7) $e = e(F, a)$ (7)

where $e_F > 0$ and $e_a < 0$. Environmental benefits to households (consumers)—net benefits received by the population from environmental services—are given by

(8) $$\Phi = \Phi(B,h)$$ (8)

where $\Phi_B > 0$ and $\Phi_h > 0$.

Having specified the production technology and the appropriate constraints, it remains to specify the objective function: that is, what is it the population would like to do (achieve) in these circumstances? Convention is followed in this treatment, by regarding the population as a single person ("a representative consumer"), for purposes of tractability. Being concerned with sustainability as we are, the "person" (population) is presumed to live forever, so their actions are described out to infinity. As noted above, the population is presumed to care about the consumption benefits they receive plus the environmental benefits they experience.

In formal terms, the dynamic optimization problem is then to maximize the social utility function

(9) $$\int_0^\infty U(C,\Phi)e^{-rt}\,dt$$ (9)

subject to $\dot{K} = F - C - a - f - h$ and Eqs. (4) and (5).

Mathematically, as stated, this is a problem in optimal control theory, with a constant discount rate assumed. To solve a complex dynamic problem of this nature, a function called the Hamiltonian is used, which, if maximized, supplies conditions that will solve the entire control problem. Essentially, we solve the problem for "one instant in time", with the conditions that solve for a single instant applying to *every* single instant of the problem. Thus it is sufficient to solve as if for "one instant" only.

The relevant Hamiltonian in this problem is

(10) $$H = U + \gamma_1\dot{K} + \gamma_2\dot{X} + \gamma_3\dot{S}$$ (10)

Linearizing U (and Φ) so that $U = U_C C + U_\Phi \Phi = U_C C + U_\Phi \Phi_B B + U_\Phi \Phi_h h$, and dividing both sides of (10) by U_C gives

(11) $$H/U_C = C + \theta_1\dot{K} + \theta_2\dot{X} + \theta_3\dot{S} + \theta_4 B + \theta_5 h$$ (11)

where $\theta_1 = \gamma_1/U_C$, $\theta_2 = \gamma_2/U_C$, $\theta_3 = \gamma_3/U_C$, $\theta_4 = U_\Phi \Phi_B \ /U_C$ and $\theta_5 = U_\Phi \Phi_h/U_C$.

It can be shown that the first-order conditions yield
$\gamma_1 = U_C = U_\Phi \Phi_h$, which makes θ_1 and $\theta_5 = 1$, so (11) can be re-written as

(12) $$MEW = C + \dot{K} + \theta_2\dot{X} + \theta_3\dot{S} + \theta_4 B + h$$ (12)

where MEW is what is termed in the literature the "measure of economic welfare." (This is analogous to the measure of economic welfare as developed in pioneering work by William Nordhaus and James Tobin in 1973.) The distinction between measures of "net product" and measures of “economic welfare” is important to appreciate, although in the above analysis they are interchangeable. Net product measures are, principally, measures of an economy’s output—measures of what can be *produced*. “Green accounting” measures of net product are generally modified to account for changes in “natural capital” (e.g. reductions in stocks of natural resources) that are not captured in the conventional market-based accounts. Measures of economic welfare are based on consumption, rather than production, possibilities, and typically include pollution flows and other elements that affect consumption and thus welfare, while not necessarily directly affecting production possibilities.

Eq. (12) can be rewritten as

$$(13) \qquad MEW = F - a - f - h + \theta_2 \dot{X} + \theta_3 \dot{S} + \theta_4 B + h \qquad (13)$$

which is similar to an expression derived by Hamilton in his 1996 paper (his equation 12) except for the following:

(i) His Φ / Φ_h equals the term $\theta_4 B + h$ here; since $\theta_4 B > 0$, this explains why he argues that his result regarding household defensive expenditure is not different from one derived by Mäler. The latter shows that such expenditure should not be subtracted from conventional GNP to get the measurement of welfare.

(ii) His model 5, which gives his Eq. (12), does not include renewable resources but the model presented here does; this is reason for the inclusion of the terms $-f$ and $\theta_3 \dot{S}$ in the RHS of Eq. (13) above.

(iii) He defines *GNP* as F and writes *GNP* instead of F in his Eq. (12); here we keep the F term, for reasons to be given below shortly.

2.2. “Sustainable” and “Optimal” Income

The analysis thus far has proceeded by following through the optimization problem to see how a fully-adjusted measure of national income can be derived in a dynamic model, by defining the relevant contributors to output and showing how they should be valued. Such a measure is characterized by optimal behavior—the population is doing the best it can given its circumstances (namely, its technology and constraints), including when resource usage and pollution are accounted for—but nothing yet has been said about sustainability. Sustainability is capable of many and varied definitions, but much of the literature in this tradition has proceeded on the basis of the fundamental definition of sustainability as non-declining utility. (This is a formal version of the famous Brundtland criterion, that future generations have, broadly speaking, the same possibilities of generating a standard of living as we do.)

Note that such a definition of sustainability is purely ends-based—it does not matter how standards of living are maintained, only that they *can* be. To reconcile optimality and sustainability here only requires that the optimal solution satisfies the condition of non-declining utility over time. There is no presumption or requirement of any kind of environmental sustainability here—it *may* be satisfied, but it need not be. In the framework we are using here, environmental sustainability is a stronger restriction and requires maintenance of individual (natural) elements in the economy.

To see this, now define an economy that operates such that the environment is not "disturbed" and stays at its pristine state. For our purposes, we shall describe this as "sustainable". (Variables at such a hypothetical "sustainable" state have been denoted by an asterisk.) In this economy, a^* is spent so that

(14) $$e = (F^*, a^*) = d(X_0) \qquad (14)$$

where $F^* = F(K, LL, R^*)$ and $R^* = g$. Therefore $X = X_0$ and $B = B_0$ for all t. Because $B = B_0$ always, there is no need for defensive expenditure, so $h = 0$. Also, because $R^* = g,\ \dot{S} = 0$ for all t.

Define the "sustainable" green NNP as

(15) $$gNNP^* = F^* - a^* - f(R^*) + \theta_4 B_0 \qquad (15)$$

This is the value of NNP when the resource stock is being maintained, as is the flow of environmental services, and there is no accumulation of pollution. "Regular" green NNP (called "*MEW*") can then be defined as *gNNP** plus deviations (called "V_i's") from that mode of activities:

(16) $$MEW = gNNP^* + \sum_{i=1}^{8} V_i \qquad (16)$$

where

(17) $$V_1 = F_L(L - LL) \le 0 \qquad (17)$$

(18) $$V_2 = F_R(R - g) \ge 0 \qquad (18)$$

(19) $$V_3 = (a^* - a) \ge 0 \qquad (19)$$

(20) $$V_4 = [\, f(R^*) - f(R)\ ] \le 0 \qquad (20)$$

(21) $$V_5 = -h \le 0 \qquad (21)$$

(22) $$V_6 = \theta_4(B - B_0) + h \le 0 \qquad (22)$$

(23) $$V_7 = \theta_2 \dot{X} \le 0 \qquad (23)$$

(24) $$V_8 = \theta_3 \dot{S} \le 0 \qquad (24)$$

Let us discuss the meanings of these terms. $V_2 + V_4$ or $V_2 - |V_4|$ is additional production due to extraction/harvest in excess of the self-regeneration rate minus additional extraction/harvest cost. So this is actually the net additional service of the (renewable) environmental asset to producers when the actual extraction/harvest exceeds the self-regeneration levels.

V_3 is the amount that actual abatement expenditure falls short of a^*, the level at which the environment would not be "disturbed." So this means the money firms save when they use the environment as a dumping place beyond natural dissipation levels. It therefore measures the additional service of the environment to producers who dispose of their wastes in the environment in excess of the natural absorptive capacity.

The above are obviously the benefits of deviating from the $gNNP^*$ mode. The costs are as follows.

The term V_1 is the cost in terms of workday loss due to the shortfall in the actual level of environment services from the $gNNP^*$ level, B_0. The term V_5 is the cost borne by consumers in terms of the defensive expenditure they are engaged in to mitigate the effects of the fall in B from B_0. Finally the term V_6 is the remaining cost borne by consumers due to the fall in B even after taking defensive actions.

It is possible to combine V_5 and V_6 into $V_5 + V_6 = \theta_4(B - B_0)$, which is the pre-defense suffering from the fall in B. But to keep V_5 and V_6 separate clarifies the picture better.

Terms V_7 and V_8 are costs in terms of depreciation. From Eq. (3), $B = -\beta \dot{X}$, so V_7 can be re-written as

(25)
$$V_7 = \theta_2' B \qquad (25)$$

Where $\theta_2' = -\theta_2 / \beta > 0$ because $\theta_2 < 0$ and $\beta > 0$ (implied by $\gamma_2 < 0$). The term V_7 is non-positive because $\dot{B}$ is. Although B is a flow variable, it can be very appropriately viewed as a measure of the state of environmental quality. Very naturally, $\dot{B} < 0$ means a deterioration in that state. Just as θ_2 measures the (marginal, negative) contribution of an increase in X to the present value of the utility stream, θ_2' measures the (marginal, positive) contribution of an increase in B. The term $\theta_2' \dot{B}$ is then the total fall in the present value of the future utility stream as a result of the fall in B. This is nothing else but the economic depreciation of environmental quality, measured as the reduction in present value of the future utility stream flowing from B (in terms of utils or U_C).

Similarly, V_8 measures the economic depreciation of renewable resources, measured again as the reduction in present value of the future utility stream flown from S (also in terms of utils).

So the sum of terms $V_1, V_2, V_3, \ldots, V_8$ actually represent the "*net benefits*" to an economy when it *deviates* from the "clean" or "sustainable" mode of production, i.e., it is the "net benefits of deviation." The items constituting the "benefits" are, as shown above, (i) the additional production due to extraction/harvest in excess of the self-regeneration rate minus additional extraction/harvest cost $(V_2 + V_4)$, and (ii) the money firms save when they use the environment as a dumping place beyond natural dissipation levels (V_3). The items of the "costs" are (i) workday loss due to the shortfall in the actual level of environment services from the pristine level (V_1), (ii) the defensive expenditure consumers are engaged in to mitigate the effects of such a fall in environmental services (V_5), (iii) remaining costs (e.g. the unpleasant feeling) borne by consumers due to such a fall in environmental services even after taking defensive actions (V_6), (iv) the economic depreciation of environmental quality (V_7), and (v) the economic depreciation of renewable resources (V_8). Together they constitute the "net benefits" of the deviation.

Since the green NNP under the "sustainable" mode is $gNNP^*$, regular green $NNP(gNNP)$ or MEW is simply the sum of $gNNP^*$ and the above net benefits of deviation. The policy implication is that a deviation is worthwhile if and only if the resultant net benefits are positive, i.e., the actual $gNNP$ exceeds $gNNP^*$; and that if it is possible at all to get positive net benefits, optimal policy is represented by the maximization of the net benefits of deviation, or alternatively by the maximization of green $NNP(gNNP)$ because $gNNP^*$, as defined, is a constant.

2.3 Comparison to "Conventional" Income

Turn now to the question of conventional NNP. Hamilton defines conventional national product as total production, F (Hamilton, 1996, p. 22), and argues in his Model 2 that a should be deducted because it is actually an "intermediate consumption." Given that intermediate consumption would not have been part of conventional NNP in the first place if it had been explicitly recorded in conventional business accounts as such, we will here simply make the assumption that either a (and f) has been recorded as an intermediate consumption (and so is not part of conventional NNP), or that it has been otherwise imputed as such and deducted. By so doing, we will define conventional NNP as $F - a - f$. We will call conventional NNP so defined "$cNNP$."

Now let us give green NNP an alternative interpretation. Under the sustainable mode

(26) $$cNNP^* = F^* - a^* - f(R^*) \qquad (26)$$

which can be thought of as a level of conventional NNP that is free from environmentally caused workday loss, but at the same time barred from enjoying any environmental services in excess of polluting at the natural dissipation rate and extracting/harvesting at the natural regeneration rate. It is basically then $gNNP^*$ minus the direct services of environment:

$$(27) \qquad cNNP^* = gNNP^* - \theta_4 B_0 \qquad (27)$$

So $cNNP^*$ is the hypothetical national product level, which on the one hand leaves the environment intact, on the other hand ignores the direct services of environment to consumers. Given this, Eq. (16) can be re-written as

$$(28) \qquad MEW = gNNP \; = \; cNNP^* + \sum_{i=1}^{5} Vi + V_6' + V_7 + V_8 \qquad (28)$$

where $V_6' = \theta_4 B + h$, which is the total post-defense direct service of the environment to consumers. The sum of the second to the last terms in the RHS of Eq. (28) can be thought of as the "net benefits of bringing the environment back into the picture (from being left intact and ignored)." Because both $cNNP^*$ and $gNNP^*$ are constants, it is obvious that the policy implications from Eq. (28) are the same as those from Eq. (16). That is, when the environment is brought back into the picture, optimal policy calls for the maximization of the net benefits of such action, because if these net benefits are maximized, so would be MEW, which measures consumers' welfare, given a constant $cNNP^*$.

It would be useful to examine the relationship among $cNNP^*$, $gNNP$ and $cNNP$. From Eq. (26), the definition of $cNNP$ given above, and the definitions of $V_i (i = 1, 2, \ldots, 4)$ given in Eqs. (17)-(20), it can be shown that the difference between $cNNP$ and $cNNP^*$ is the sum of V_1, V_2, V_3, and V_4. This is not hard to understand: $cNNP^*$ is the gross production F^* based on $L = LL$ and $R = g$, minus a^* (the hypothetical abatement expenditure to keep the environment at its pristine level) and minus $f(R^*)$, which is the extraction/harvest cost when the level of extraction is such that the stock of renewable resources remain intact; $cNNP$ consists of these same items but all at actual rather than hypothetical levels of spending. The difference between the two are (i) V_1, which catches the fall in gross production from F^* when there is workday loss caused by the actual supply of labor falling short of LL as a result of the fall in environmental services from its pristine level, (ii) V_2, which catches the rise in gross production level from F^* when the actual level of extracting the renewable resource, *R*, exceeds its self regeneration level, g, (iii) V_3, which catches the difference between a^* and a (the actual and lower abatement expenditure), and (iv) V_4, which is the difference between $f(R^*)$ and $f(R)$, the actual, higher extraction/harvest cost.

Given $V_4 = -|V_4|$, we can then re-write Eq. (28) as

$$(29) \qquad \begin{aligned} MEW = gNNP &= cNNP^* + V_1 + (V_2 - |V_4|) + V_3 + \sum_{i=5,7,8} V_i + V_6' \\ &= cNNP^* + (cNNP - cNNP^*) + \sum_{i=5,7,8} V_i + V_6' \end{aligned} \qquad (29)$$

That is, the algebraic difference between $cNNP$ and $cNNP^*$ consists of the terms involving V_1 to V_4. In other words, when the environment is brought back into the picture, benefits $V_2 - |V_4|$ (net receipts from additional extraction/harvest) and V_3 (waste disposal), and damage V_1 (workday loss) would have been recorded by the conventional NNP. But conventional NNP is obviously an unsatisfactory candidate to maximize, because the entire term $\sum_{i=5,7,8} V_i + V_6'$ is left out. And this is precisely why the green accounting exercise is valuable. Together, V_5 (the negative of consumers' defensive spending), V_6' (total post-defense direct service of the environment to consumers), V_7 (economic depreciation of environmental quality), and V_8 (economic depreciation of renewable resources) constitute the terms for which adjustments in conventional NNP are needed in order to derive a green NNP ($gNNP$) or MEW, that is an appropriate target to maximize.

3. The SEEA and ENRAP Approaches and the Green NNP

3.1 Introduction

Practical revisions to national accounting systems have typically not been constructed from theoretical principles. The purpose of this section is to analyze two key such accounting systems in the light of the preceding theoretical analysis.

The United Nations has been engaged in modifying the official system of national accounts, under the label SEEA (System of Integrated Environmental and Economic Accounting). In this section we compare the approaches identified from the foregoing theoretical discussion with the adjusted measures of income presented in the SEEA, and also with the ENRAP system associated with Henry Peskin.

SEEA (Version IV.2 in 1993, 1998) defines EDPI as NNP minus "depletion" of natural resources and EDPII as EDPI minus "degradation" of natural resources. The depletion is estimated at net rent cost (otherwise known as the "net price" valuation; recommended for all resources), or at user-cost (otherwise known as the El Serafy valuation; recommended for exhaustible resources—see the companion paper by Atkinson and Dietz for further discussion), while degradation is estimated at the hypothetical abatement cost of bringing down pollution from the existing (post-treatment) level to a level that does not harm the environment (called "maintenance cost").

ENRAP has the "factor cost" and the "expenditure" side of the accounts. On the former side, adjustments to conventional NNP come from waste disposal services (a negative number, as it is seen as a "subsidy" from nature) plus "net environmental benefits" minus "depreciation of 'natural assets' such as minerals, forests and fishery" On the latter side, adjustments to conventional NNP come from deducting the environmental damages (workday loss and medical costs), adding direct services of the environment to consumers and then deducting "depreciation of natural assets." Because ENRAP's "net environmental benefits" are defined as waste disposal services (at its absolute value) minus damages plus direct services of the environment, if the latter two terms were zero, waste disposal services (at its negative value) and "net environmental benefits" would have cancelled each other out, and there would be no adjustment except for the "depreciation of environmental assets." So the essence of the green NNP concept under ENRAP are damages (to be subtracted from $cNNP$) and direct services of the environment (to be added to $cNNP$), both on the "expenditure" side of its accounts.

In addition, in the implementation of ENRAP in the Philippines, the "depreciation of environmental assets" seems to have included only the quantitative aspect of environmental depletion. Here Peskin emphasizes that the ENRAP valuation of "depreciation" is based on economic rather than net rent cost, i.e., it is the difference in the present values of net future services from the assets between periods.

Recently the United Nations appointed a group of experts, called the London Group, to revise SEEA. A draft has been put on the web. In the latest version, it is clear that the basic spirit of subtracting the depletion of natural (non-produced) resources from traditional GNP to get an environmentally adjusted NNP (hereafter known as eaNNP) is maintained. But it is obvious that while in the 1993 (and 1998) version, the net price and El Serafy's methods are highlighted, they are alluded to as "special cases" of the present value method, which the 2002 version sticks to (see chapters 7, 8, and 10). Using non-produced biological resources as an example, "depletion-adjusted" NNP is conventional NNP minus the difference between two present values of (non-produced) natural resources at respectively the beginning and the end of the accounting period.

As for the subtraction of degradation, the London Group mentions at least three different approaches (see chapters 9 and 10). One is called "cost-based" (this version of eaNNP will be hereafter known as ceaNNP), which is basically the same as EDPII in the 1993 version. That is, ceaNNP equals conventional NNP minus depletion and minus maintenance cost. Maintenance cost is the amount of spending that would have had to be spent to avoid environmental degradation that has actually happened, using current cost estimates under current technologies.

The second option is to deduct damages to the economy that have occurred from actual pollution from the conventional NNP. The result is called "damage-based" NNP (this version of eaNNP will be called deaNNP hereafter, although it is called daNNI or damaged-adjusted net national income by the London Group).

The third option is to design a model, which takes into account economic behavior, and calculate a GNP (or NNP) that is based on the economy operating under a certain set of constraints, which constitute the researcher's idea of how to put the long-term economic growth (and the associated social welfare) of the society on a more "sustainable" path. The interest then focuses not on the resultant new aggregate, "but in the gap between the existing economy and the greened version". This version of the green GNP is named "greened economy GNP" or geGNP in the report of the London Group. In this paper, it will be referred to as geNNP for consistency in the use of terms.

With the above introduction, let us now start comparing the different approaches with the system of equations developed in the last section.

3.2 Depletion of Natural Resources

With respect to depletion (the quantitative aspect of depreciation) of natural assets, the SEEA and ENRAP methods are the same in deducting it from conventional NNP to get *gNNP*, but the method of valuation is different, at least in the area of renewable resources. It is obvious from Eq. (24) and the subsequent explanation that the present value approach, recommended by both the London Group and ENRAP is more sound economically.

It may be argued that the net rent approach, calculated as the amount of resources being extracted or harvested times its current price, is easier to estimate, and that the choice of that method is merely a matter of the method of valuation: it does not reflect any substantive difference from the economic depreciation approach recommended by ENRAP. (To be sure, the two approaches are equivalent under the condition that the net rent always appreciates at the discount rate, a situation otherwise known as the Hotelling rule, which would have been the case if there were perfect competition and foresight. In reality, this condition is unlikely to hold, especially for publicly owned natural resources)

Upon closer examination, such a view does not seem to hold. The green accounting system as derived in Eq. (28) has important implications for optimal policy-making. Let us concentrate now on terms $V_2 - |V_4|$ and V_8. The former is net benefits (addition to current consumption) from extraction/harvesting beyond natural re-generation, the latter is the depreciation in the value of the natural assets being so extracted/harvested. The former is therefore the "benefit" in terms of additional *current* consumption, and the latter the "cost" in terms of forgone *future* consumption. Optimal policy calls for choosing the level of extra extraction/harvesting that would maximize $(V_2 - |V_4|) - |V_8|$.

Now if the latter is valued at the net rent approach, it is de facto valued at the term $V_2 - |V_4|$, so the sum of the two terms, namely $(V_2 - |V_4|) + V_8$ or alternatively $(V_2 - |V_4|) - |V_8|$ would always be zero, *regardless of the level of extra extraction/harvest*. This would therefore deprive the net rent approach from giving useful information about the optimal level of extra extraction/harvesting to be chosen by policy-makers. (If the Hotelling rule prevails, there is nothing wrong with such a result: there could be no net gains or losses from deviating from the "sustainable" mode.)

But of course, to deduct something from the conventional NNP is still better than deducting nothing. Conventional NNP or $cNNP$ would lead us to think that any extra extraction/harvesting is worthwhile, because the consequences for the future are not accounted for. Those 1993 and 1998 SEEA accounts that adopt the net rent approach adjust the conventional NNP by removing the value of such extra extraction/harvesting completely. By contrast, those SEEA accounts that use the El Serafy approach would not suffer from such a shortcoming. But the El Serafy approach would be equivalent to the present value approach only under an assumption that is also very restrictive, namely that the net rent is constant and positive, and then drops to zero when the resource is exhausted.

3.3 Degradation of the Quality of Natural Resources

The ideal expression of this term should be Eq. (25), i.e., the fall in the present value of the future flow of direct environmental services. It is therefore the economic depreciation of B, which can be thought of as an index of environmental quality.

The SEEA approach is to value it in terms of "maintenance cost" as explained above. This appears to be a good candidate for valuing the depreciation in environmental quality. But upon closer examination, a different story emerges.

The "maintenance cost" is simply V_3 in Eq. (19), the saved cost from reduction in abatement efforts. To value V_7 in Eq. (25) at V_3 is to value the sum of $V_3 + V_7$ or alternatively $V_3 - |V_7|$ always at zero. But this would deprive the green accounting from being useful in optimal policy-making, as in the case of depletion of natural resources discussed above.

Similar to the case above, the benefit in terms of additional *current* consumption of the degradation of the quality of natural resources from extra pollution, i.e., polluting beyond the natural dissipation level, should be weighed against the cost of doing so, in terms of the foregone *future* consumption (fall in the present value of the future stream of direct environmental services). So optimal extra pollution calls for the maximization of $V_3 - |V_7|$, V_3 being the benefit and $|V_7|$ being the cost. To value $V_3 - |V_7|$ at zero *regardless of the level of extra pollution*, as SEEA does, prevents it from being a useful decision-making tool. (Many theoretical derivations of an ideal measure of "green national income" or "green national product" have the implication that it is the damages of pollution (valued at marginal social costs) that should be subtracted from the regular GNP (rather than the "maintenance cost"), but the current treatment exposes the problem by using the concept of green accounting as "sustainable green income" plus deviations from that level of income, thus making the undesirable consequence of subtracting the maintenance cost much clearer.)

But here again, to deduct the maintenance cost is better than no deduction. If there were no deduction, all the saved abatement cost would appear as additional consumption or national product, while the sacrifice in terms of the fall in future stream of consumption would not be accounted for. SEEA's EDPII knocks out the saved abatement cost (or benefit from extra pollution, in terms of additional current consumption) completely.

Turn now to ENRAP. The term V_7 does not appear explicitly in ENRAP's handling of "depreciation" of natural resources, which is confined to the quantitative aspect. Since ENRAP does have a term measuring direct services of the environment, the absence of this term looks strange: it would be more consistent if ENRAP contained an item (in the capital account) that records the change in the present value of future stream of direct services of environment, that results from pollution in the current period. Maybe this is what future revisions of ENRAP can take into account.

It is possible to seek an alternative interpretation of ENRAP's "damages." They can be regarded as a measure of loss of consumer's utility in the current period, under the assumption that there are no damages in the future periods. That is, all damages caused by pollution are borne by consumers in the current period. The model presented here would then not be a suitable tool because it assumes the side effects of pollution would affect only future stream of services. It is possible to re-design the model to analyze the problem, and this will be done in the section below.

3.4 Defensive Spending by Consumers and Direct Services of the Environment to Consumers

While adjusting the conventional NNP for environmental effects, whether to deduct "defensive spending" by consumers has been a point of contention amongst analysts. Hamilton's formulation (in his 1996 paper, equation 12) first subtracts such spending from conventional national product, but then adds a term (the contribution of Φ), which he says would be higher than the original amount subtracted.

It is clear from Eq. (29) and the definition of V_6' in Eq. (28) that the answer actually depends on the method of estimation of "direct services of environment to consumers." If it is estimated at *pre-defense* levels (the first term in V_6'), there is no need to deduct h (the term V_5), because it would have been cancelled out by the addition of h according to the second term in V_6'. If, on the other hand, the direct services of environment to consumers has been estimated at *post-defense* levels (so it is the entire V_6', or alternatively, the entire contribution of Φ rather than merely B), then apparently there is a need to deduct h according to V_5.

This is not surprising. From Eq. (9), utility is a function of C and Φ, the latter is in turn a function of B and h according to Eq. (8), and C and h are homogeneous products. Since both C and h work to enhance U, the distinction is actually arbitrary given the general functional form employed in the equations. This is why in the end, in the derived Hamiltonian (measured in U_C) in Eq. (16), there is actually no distinction between C and h. So whatever has been subtracted according to V_5, must be added back according to the second term in V_6' . Put another way, the appropriate treatment of defensive expenditure h depends on whether our benchmark is utility pre-defense or post-defense. This has clarified the picture, we hope.

Turn now to the SEEA and ENRAP. It is clear from the first term in V_6' that when adjusting the conventional NNP for environmental effects, direct services of the environment to consumers should be added, according to Eq. (29). Neither SEEA's EDPI nor EDPII catches this item, while ENRAP does have an item called "direct nature services," which basically includes the imputed services of recreation. So SEEA does not handle the problem while ENRAP handles it in a limited way.

But admittedly it is very hard to measure the *total* value of *all* direct environmental services (air, water, recreation and so on) to consumers. For this reason, it may be advisable to estimate the (negative) value of the *change* in quality of environment from B_0 to actual B instead. Because B_0 is a constant, such an action would not affect the policy implication of green accounting. That is, instead of using the formulation in Eq. (29), we can use

$$(30) \qquad MEW \equiv gNNP = cNNP* + (cNNP - cNNP*) + \sum_{i=5,6,7,8} V_i + \theta_4 B_0 \qquad (30)$$

and not actually estimate the last term in the RHS, as it is some constant. The first term of V_6 then measures the decrease in utility enjoyed by the consumers in the current period due to the fall in the quality of environment from its "sustainable" level, according to Eq. (22).

There is, of course, a way to get rid of B completely. Assuming all damages from pollution affect utility in the current period only, and ignoring extraction of natural resources (or S) here, we can re-formulate the system as a problem of maximizing

$$(31) \qquad \int_0^\infty U(C,\Phi) e^{-rt} dt \qquad (31)$$

subject to

$$(32) \qquad \dot{K} = F - C - a - h \qquad (32)$$

In addition,

$$(33) \qquad F = F(L,K) \qquad (33)$$

$$(34) \qquad L = LL - g(e - e_0) \qquad (34)$$

where e_0 is a level of harmless emission that equals the natural dissipation rate,

$$(35) \qquad \Phi = \Phi(e - e_0, h) \qquad (35)$$

and

$$(36) \qquad e = e(F, a) \qquad (36)$$

It can be shown that the resultant Hamiltonian measured in utility units could be written as

$$(37) \qquad MEW \equiv gNNP = F(L,K) - a - h + \lambda(e - e_0) + h \qquad (37)$$

after using the first-order conditions, where $\lambda = (U_\Phi / U_C)[\partial\Phi / \partial(e - e_0)]$. Assuming as before conventional NNP equals $F(L,K) - a$, and canceling terms, we have

$$(38)\, MEW \equiv gNNP = cNNP^* + (cNNP - cNNP^*) + \lambda(e - e_0)$$

where

$$cNNP^* = F(LL,K)$$

i. e., the “hypothetical” NNP at the “sustainable” level. So the term actually measures the decrease in national product resulting from pollution-caused workday loss, while the last term (in the RHS of Eq. (38)) measures the decrease in real national product resulting from polluting beyond the natural dissipation level.

Eq. (38) is, we believe, as close to the ENRAP framework as we can get (ignoring the issue of resource extraction, which has already been discussed above). ENRAP’s “damages,” consisting of workday loss and medical costs (as well as damages on property, an issue not considered in the model), can be thought of as measures of the second and third term in Eq. (38). Here it seems that because ENRAP deducts workday loss from actual instead of the hypothetical conventional NNP to get its green NNP, there might have been double subtractions, because actual conventional NNP would have already reflected such losses. This is a point that can be taken into consideration in the future revision of ENRAP.

In addition, medical costs might have been able to catch only part of the effect of increased pollution. When the quality of environment falls from a pristine to a mediocre level, consumer’s welfare would have been adversely affected even in the absence of medical care expenses (or workday loss), the latter emerging when the quality falls further to hazardous levels. So medical costs would under-estimate the fall in the utility caused by $e - e_0$. This is another point that can be taken into consideration in the future revision of ENRAP.

The London Group’s deaNNP (defined above) is similar to the ENRAP approach in that it too deducts damages from conventional NNP. That is, an environmentally adjusted aggregate measure should be defined as conventional NNP minus environmental damages defined as the fall in consumers’ utility as a result of polluting beyond the “natural dissipation” level. When damages are confined to those done to human health, as expressed in London Group’s definition of daNNI, they can be measured in terms of the willingness to pay to avoid an environmentally caused deterioration in health-related welfare (our utility).

In the actual imputation of such willingness to pay, all avoidance cost, including consumer expenditure on environmental improvement and medical expenditure should be included. If such cost is regarded as "consumer defensive expenditure," then it can be said that deaNDP argues for its exclusion. Specifically, Eq. (38) can be re-written as $MEW = cNNP - h + \lambda(e - e_0) + h$. Suppose a person suffers from say, air pollution, and has chosen to spent on air filters as well as medical services to restore his or her health. The post-defense or post-restoration level of services from the environment would be $\lambda(e - e_0) + h$, which can be regarded as zero (as if nothing had happened). Then the entire defensive expenditure has to be deducted from *cNNP*. In many cases complete restoration is not possible (or not chosen), so the term $\lambda(e - e_0) + h$ would be smaller than zero. In these cases, deaNDP would not only deduct all consumer defensive expenditure from the conventional NDP, but should also deduct (from the constant) the deterioration in welfare associated with the shortfalls from the "normal" level of direct services from the environment as a result of post-defense poor health.

4. Conclusion and a Brief Discussion of the Use of Models

Among the three basic variants of approaches to the issue of green accounting reviewed above, namely the SEEA's EDPII, the ENRAP, and the London Group's deaNNP, the distance from the third one to the theoretically ideal system of green accounts (in Eqs. (29) or (38)) is the smallest, followed by that from the ENRAP, and still followed by the SEEA, which leaves much room for improvements. This said, it should be emphasized that all approaches (including SEEA's EDPII) have their merits when compared to the situation of no adjustments in the conventional national product, which leaves a far greater room for improvements as it ignores almost all of the important aspects of environment-related costs and benefits.

The SEEA's handling of environmental depletion (the "net rent" version) and environmental degradation is basically that of surgical removal. It can be interpreted as saying that these values should not be part of national product, thereby de facto assuming the net benefit from pollution/extraction/harvest beyond sustainable levels is always zero, until better ways of valuation of such net benefit exist and can be brought back in. Given the difficulties in the estimation of net benefits, such an option is perhaps not a bad first step to be taken by the statistics authorities, who typically care a lot about "standardization."

Moreover, EDPII and the related EDPI are only two of the numbers in the entire system of satellite accounts advocated by SEEA. In the "environmental assets" accounts, there are such items as "other accumulation," "other volume changes," and "revaluation." These can be used along with other variables that need to be collected/estimated to compile an estimation of the true economic depreciation of tangible environment assets, and thereby assessing the policy implication with respect to optimal extraction/harvest. In fact, many researchers have found that the compilation of the detailed SEEA satellite accounts, which record environment-related expenditures by sectors, in addition to the assets accounts by different types of environmental assets, is extremely useful both as a tool to gather valuable information and as a pool of data from which different researchers can draw different elements for their different studies. So the SEEA statistics scheme is definitely a worthwhile exercise.

The ENRAP system is close to the ideal system presented above, and is therefore recommended, particularly if green accounting is to be used for environmental policy decision-making. It would, however, be even closer, if the following strengthening can take place in the future.

First, for pollution and improper solid waste disposal that would have long-lasting cumulative effects (and therefore the model pertaining to Eq. (29) prevails), changes in the direct service of the environment resulting from such effects (remembering Eq. (30) and the first term in the RHS of Eq. (22)) should be more carefully recorded in two ways:

(i) Broadening the effects of decrease in the quality of environmental service by including not only changes in recreational values and the incurred medical costs, but also reduced satisfaction resulting from the fall in environmental quality even though it has not yet reached hazardous levels.

(ii) Adding a second dimension to "depreciation," to include not only changes in the present value of future stream of services from extractable/harvestable natural assets, but also from assets that generate direct services to consumers such as scenery. So if wastes have been improperly disposed, and their cumulative effects adversely affect the quality of the future stream of such services, the resultant "depreciation" (remembering Eq. (25)) should be estimated and subtracted from conventional NNP.

Secondly, for pollution that affects consumers in the current period only (most likely those types of air pollution that have few cumulative effects to speak of), and therefore the model pertaining to Eq. (38) prevails, it is again advisable to broaden the definition of "damages" to include reduced satisfaction resulting from degrading environmental quality even before it reaches hazardous levels.

Thirdly, the appropriateness of subtracting workday loss can be re-assessed. Although it is rightly part of damages that are to be weighed against the benefits (from additional waste disposal services) in policy considerations, its effects are already caught by conventional NNP. In other words, it is not the difference between the *actual* conventional NNP $(cNNP)$ and green NNP $(gNNP)$ that needs to be maximized in the choice of policies, it should be the difference between the hypothetical "sustainable" conventional NNP $(cNNP^*)$ and green NNP (remembering Eqs. (29) and (38)).

Finally, as for the work done by the London Group, the preliminary results are very promising. They are very close to the theoretically correct definition of green national product, and they are similar to the ENRAP approach in many aspects. In the above discussion, it should by now be clear that the approaches recommended or mentioned by the London Group with regard to adjustment for depletion of natural resources, and adjustment for damage-based depreciation of environmental quality, are both theoretically sound. The ceaNNP, which is similar to the SEEA EDPII measure, is not, however, recommended, for reasons given above.

One last concept introduced earlier but not really discussed is that of geNNP, or a model-based green national product. The current model is not adequate to address this problem, because it does not involve behavioral specifications. The model is designed as if everything can be determined by a central planning agency. In the real world, market exists and authorities typically achieve policy goals not by directly ordering changes, but by re-designing the incentive structure. It would therefore be desirable to extend the current model to one that includes behavioral responses to different policy measures.

But this is not easy to do at an abstract level, especially when the underlining structures are quite different across countries. Computable or applied general equilibrium models are more suitable tools to use, and they are explicitly mentioned by the London Group. So the geNNP can be considered an approach that is both theoretically superior (to the abstract model in the current paper) and empirically useful, and is highly recommended. It is worth mentioning that there are some similarities between geNNP and the concept of sustainable green NNP or $gNNP^*$ in the current model. If, under certain specifications, the long-term social welfare maximizing $geNNP$ is one that will keep the total stock of renewable resources intact, and that will never pollute beyond the natural dissipation level, then it becomes $gNNP^*$ in our model. While this may be judged too high a standard by some, it may be judged as an adequate standard by others, especially those strongly committed to environmental protection.

There is admittedly a trade-off inherent in the green national product accounting exercise. If it were to follow standardized rules that are easy for the statistics officials to implement, it would carry only a small amount of information useful for policy-making purposes. On the other hand, if it were to follow theoretically sound rules, the implementation could be a formable task, which is also likely to invite controversies. The compromise, which is already in the making, is for the authorities to try to obtain as much information around the *individual variables* in the "ideal" type of green accounting as possible, and leave it to the academics to collect additionally required data and meanwhile develop specific green accounting models to address specific problems. Such a division of labor seems to be able to strike a balance between rigorous theories and existing controversies around implementation.

Green national product accounting so implemented could be a very important step towards the correction of national product measures, the use of which have been very popular but under many circumstances misleading, because they are often equated, explicitly or implicitly, with measures of welfare. It is time to develop statistics that more closely reflect true human welfare. The green accounting exercise and other even more broadly-minded attempts such as Nordhaus-Tobin (1973) and Daly-Cobb (1989), are efforts that have long been overdue.

Glossary

Natural Resource Accounting: Accounting procedure that takes into account the use or renewal of natural resources in the production of a nation's output.

Green National Product: A modified version of the traditional concepts of national products such as Net National Product (NNP); the modification mainly involves subtracting from the traditional measure the costs of natural resources depletion and degradation that are not otherwise recorded as well as adding to the traditional measure similarly unrecorded benefits of natural resources services.

SEEA: Formally the "System of Integrated Environmental and Economic Accounting", which was an effort made by the Statistics Division of the Department of Economic and Social Affairs, United Nations in 1998 on modifying the traditional concepts of national product by taking into account the cost of the degradation of the environment and the depletion of natural resources.

ENRAP: Formally the "Environmental and Natural Resources Accounting Project" implemented in the Philippines, the report of which was published by the International Resources Group (IRG), Edgevale Associates (EA) and Resources, Environment and Economics Center for Studies (REECS) in 1996; it was also an attempt to modify the traditional concepts of national product by taking into account the cost of the degradation of the environment and the depletion of natural resources, but it adopted methods different from SEEA's.

Hamiltonian: A mathematical expression often used to solve problems of optimal controls; specifically, if one wishes to maximize an objective function (defined over a period of time or "dynamic") subject to constraints (also dynamic) one can formulate a function called the Hamiltonian, which, if maximized, supplies conditions that will solve the entire control problem; the Hamiltonian is defined for "one instant in time", but the conditions that solve for this single instant would apply to *every* single instant of the problem.

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Biographical Sketch

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