Green Accounting and Environmental Efficiency Indexes*

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Abstract

We derive a theoretically consistent welfare measure that is to be interpreted as a 'green' net national product (NNP). In our framework, environmental deterioration is modelled as an undesirable, but inherent by-product of economic activities consuming the resource base. A major advantage of our approach is that, instead of using shadow prices of pollution that are not readily available, we can focus on quantitative data on consumption baskets of desirable (goods) and undesirable (pollution) outputs actually chosen by societies. This issue has not been discussed in the context of green national income accounts to date, and here we show that this omission is partly a result of a tradition of modelling pollution as an unpriced input in growth models. Accordingly, the shadow value of pollution has been determined by preferences that have been distinguished from consumption choices. We suggest, instead, that environmental efficiency indexes based on outputs of firms or industries could be used as weights in green NNP calculations for the adjustment of environmental effects.

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NON TECHNICAL SUMMARY

We derive a theoretically consistent welfare measure that is to be interpreted as a 'green' net national product (NNP). In our framework, environmental deterioration is modelled as an undesirable, but inherent by-product of economic activities consuming the resource base.

We start with a simple growth model in which output is divided into investment ('intermediate good') and consumption of desirable output ('goods') and undesirable output (pollution). Capital stock incorporates both the manufactured means of production (equipment) and the resource base (natural resources). Since pollution consumes the resource base of the economy, it is a source of inefficiency in the sense that the less the economy pollutes the more efficiently it uses its resources. For the sake of comparison we separate in our second model different types of capital into man-made and natural capital to show that our results do not depend on the broad interpretation of capital stock. We illustrate the implications for NNP measurement and, in section 4 in particular, discuss the implementability of our measurement rule.

In the recent production theory literature, there has been an increasing interest in including the production of by-products such as pollution in the measurement of productivity. The goal is to measure firms' environmental performance with efficiency indexes that include undesirable outputs but do not require information on shadow prices. Modelling of productivity and undesirable outputs originated with the work by Pittman (1983) which has later been extended into various applications in environmental economics; see, e.g., Färe et al. (1989), Brännlund et al. (1995), Hetemäki (1996). This issue has not been discussed in the context of green national income accounts, and here we show that this is partly a result of a tradition of modelling pollution externalities in growth models, e.g., Solow (1986), Mäler (1991), Hartwick (1990), Asheim (1994), Aronsson, Johansson and Löfgren (1997). We suggest an only slightly modified interpretation of a theoretical analysis in the hope that it will shed light on the possibilities that productivity measurement can offer in green accounting. The framework has interesting implications for practical accounting work.

Instead of guessing people's preferences, we should look more carefully at current consumption choices and production technologies. What we can do is to measure the amounts of undesirable outputs even though we do not know their correct shadow prices. Using efficiency measurement, we can determine the weights to be used in green NNP calculations for taking into account the environmental effects of production and consumption.

Key words: national income accounting, environmental efficiency, technology parameters.
JEL: Q20

1 Introduction

Economists have – at least in theory – agreed upon the basic principles of how to incorporate environmental deterioration and resource depletion in national income accounts. Using Weitzman's (1976) article as an analytical cornerstone, several authors have indicated that a national welfare measure along the lines of a 'green' net national product (NNP) should appropriately measure and price changes in natural resource stocks as well as external effects of economic activities on the environment.[1]

Suggestions on how to calculate the 'ideal' NNP in practice have been fewer. The reason is also evident: even though market prices do not necessarily reflect the pollution impacts of goods consumed in the economy, the shadow prices used in accounting to correct market prices are difficult to calculate. It seems to have become standard procedure to use observed prices and quantities for adjustments in the NNP and to *assume* that they do not deviate too much from the 'ideal' ones. Of course, this is an unsatisfactory compromise which calls for alternative solutions.

A recent proposal, made by Aronsson and Löfgren (1998), is that willingness-to-pay information should be used to obtain the appropriate shadow prices for environmental deterioration. Consumers would then be asked about their willingness to pay, for example, to reduce the effects of pollution. This information would necessarily capture in monetary terms all the externalities associated with the use of natural/environmental resources (including option values as motivation for conservation). Besides the practical problems that a continuous valuation procedure would require, a more challenging question is how the choices observed in the markets should be interpreted if consumers are assumed to behave environmentally rationally. Our aim here is to shift the focus of green national income accounting from not-easily-measurable shadow prices towards quantities, or the annual consumption baskets with corresponding pollution impacts actually chosen by societies. A major motivation for elaboration in this direction is that the theoretically derived measurement rules should also be implementable in practice. Therefore, we believe that the theory may have something to draw from measurement.

When a green NNP is calculated in practice, the measurement of economic activity

[1] See, e.g., Solow (1986), Mäler (1991), Hartwick (1990), Asheim (1994), Aronsson, Johansson and Löfgren (1997).

is based on market transactions and market prices. This means that we do not know whether, or to what extent, pollution effects are one of the considerations when purchases are made; especially when prices do not signal this information for economic agents. It would be reasonable, however, to think that the quantity and quality of consumption as such capture some information on preferences also with regard to pollution. Consumption commodities differ in their attributes and, at least in principle, the pollution impacts of goods can be measured. This is why we believe that we should not pretend that economic agents are wholly unaware of pollution impacts and that we therefore only need adjust prices afterwards for extended green accounts. Instead, we should concentrate on correcting the quantity or quality side of actual transactions in the markets.

To motivate our approach, consider, for example, a range of eco-labelled products which are already traded in the markets, signalling that environmental impacts affect production and consumption patterns. The environmental impacts of products can in principle be traced back to the technology used both in the production and the ultimate disposal of goods. In other words, different production technologies imply different environmental performance. Then the best available technology from a pollution point of view could be used as a point of reference when relative pollution impacts of produced and consumed goods are to be measured. Using pollution impact parameters determined by technology, we would arrive at weights to be used in green NNP calculations for taking into account the environmental effects of production and consumption.

In the recent production theory literature, there has been an increasing interest in including the production of by-products such as pollution in the measurement of productivity. The goal is to measure firms' environmental performance with efficiency indexes that include undesirable outputs but do not require information on shadow prices.[2] This issue has not been discussed in the context of green national income accounts, and here we show that this is partly a result of a tradition of modelling pollution externalities in growth models. We suggest an only slightly modified interpretation of a theoretical analysis in the hope that it will shed light on the possibilities that productivity measurement

[2]See, e.g., Chung et al. (1997). Modelling of productivity and undesirable outputs originated with the work by Pittman (1983) which has later been extended into various approaches; see, e.g., Färe et al. (1989), Brännlund et al. (1995), Hetemäki (1996). Tyteca (1996) gives an overview with a comprehensive bibliography.

can offer in green accounting. The framework has interesting implications for practical accounting work.

We start with a simple growth model in which output is divided into investment ('intermediate good') and consumption of desirable output ('goods') and undesirable output (pollution). Capital stock incorporates both the manufactured means of production (equipment) and the resource base (natural resources). Since pollution consumes the resource base of the economy, it is a source of inefficiency in the sense that the less the economy pollutes the more efficiently it uses its resources. For the sake of comparison we separate in our second model different types of capital into man-made and natural capital to show that our results do not depend on the broad interpretation of capital stock. We illustrate the implications for NNP measurement and, in section 4 in particular, discuss the implementability of our measurement rule.

2 Model I

Our analytical framework is based on the result of Weitzman (1976) which proves how net national welfare measurement can be theoretically justified. The well-known result states the valuation principle for an economy maximizing utility subject to capital stock over time. Utility is derived from consumption, C, whereas the accumulation of capital, $\dot{k} = f(k) - C$, is determined by total output, $f(k)$, minus consumption, i.e., investments, I. As shown by Weitzman, a linear support of the Hamiltonian along the optimal path corresponds to national welfare, or NNP$= C + f(k) - C = C + I$.

We use the above accounting rule as a guiding principle to build up the theoretical model. We define the capital stock such that we can explicitly take into account pollution or environmental effects on the whole resource base including natural capital. Utility function $U(C)$ is strictly increasing, strongly concave and discounted over time by a constant social interest rate $\delta > 0$. The plan is to maximize

$$\int_0^\infty U(C)e^{-\delta t}dt \tag{1}$$

subject to the capital stock equation

$$\dot{X} = g(X, P) - C - z(W). \tag{2}$$

Capital, X, is to be understood in its broadest sense: it is both natural and man-made capital. The motivation is that natural resources, as an 'original' capital stock, are transformed by labor into a 'manufactured' capital stock.[3] Accordingly, we posit a production function, g, which subsumes both natural production (growth of the renewable natural resource base) as well as conventional production (man-made production).

Pollution/damage is caused by consuming environmental reserves. In other words, pollution is not a production input which later turns out to be harmful and accumulates in a stock over time. Pollution is simply an *inherent by-product of economic activities* that deteriorates natural capital, or resource base by affecting its growth negatively or depleting the stock directly. The pollution intensity of output is related to consumption and is captured by parameters α and β; pollution, $P = \beta C$, affects negatively the production function ($g_P < 0$), and $W = \alpha C$ captures the direct effects of consumption of the capital stock (e.g., raw-material extraction, waste flows deteriorating the stock; if $\alpha = 0, z(W) = z(0) = 0$).

To understand the goal of our modelling it is important to emphasize that pollution is to be interpreted here as a source of inefficiency. That is why our model differs from the work by, e.g., Tahvonen and Kuuluvainen (1993) and Aronsson and Löfgren (1998), which have been influenced by the model of Brock (1977). In Brock's model pollution enters into the economy as a consumption externality through preferences as a separate argument in the utility function and therefore inevitably decreases utility directly (as it may also do; it is not our purpose here to take a position on this issue as such). A similar modelling of pollution in a purely mathematical sense is adopted in Hartwick (1990) where pollution stock is a negative argument in the production function. This, however, implies negative 'preferences' on the part of firms towards pollution, which contrasts with the spirit adopted by Brock, who considers pollution as a positive externality on the producers' side. What is common to all of these models, however, is that the shadow

[3] In the next section, we will discuss the case in which natural and man-made capital are separate stocks to see whether this distinction provides any additional insight.

value of pollution is determined by preferences that are distinguished from consumption choices.

In our model we focus strictly on the direct pollution impacts of production and consumption on the resource base and therefore need not assume that people are 'greenish' in the sense that they care about pollution as a separate issue as such; they only care about material well-being, C, even though it is known that the environmental impacts of C vary according to the composition of consumption and the technology of production. While this distinction may sound pedantic at this stage, it will play an important role when we discuss its implications in correcting for environmental effects in NNP.

For the utility maximization problem of an economy, we write the current value Hamiltonian

$$\mathcal{H} = U(C) + \lambda(g(X,P) - C - z(W)) \tag{3}$$

and the first order conditions

$$\begin{aligned} \partial\mathcal{H}/\partial C &= U_C + \lambda g_P \beta - \lambda - \lambda z_W \alpha = 0 && (4) \\ \dot{\lambda} &= \lambda(\delta - g_X) && (5) \\ \dot{X} &= g(X,P) - C - z(W). && (6) \end{aligned}$$

We can readily give an intuitive interpretation for equation (4): optimal consumption, C, is lower (U_C is greater) whenever there is pollution (α and/or β are greater than zero). To arrive at a monetary value measure of a NNP we linearize the utility function, $U(C) = U_C \cdot C$, and divide the current value Hamiltonian by λ $(= U_C/(1 + z_W\alpha - g_P\beta))$

$$\mathrm{NNP} = \underbrace{(\underbrace{1 + z_W\alpha - g_P\beta}_{=\Delta\geq 1}) \cdot C}_{C^*} + \underbrace{\underbrace{g(X,P) - C - z(W)}_{\text{investment}}}_{\dot{X}^*}. \tag{7}$$

Now we are in a position to see how the conventional NNP should be adjusted using pollution intensity of consumption to account for environmental consumption and its impact on the Hicksian concept of income, or the maximum amount that can be consumed while still leaving capital intact. In the above equation, C stands for consumption of *measured* desirable output (pollution excluded) and $C*$ for total consumption of both desirable and undesirable output (pollution included; $C* = \Delta C$). Hereafter we refer to Δ as a correction factor, since it corrects the quality of output for the effects of the measurable emissions (z_W and g_P) and pollution intensity (α, β). If pollution were zero, i.e., $\alpha = \beta = 0$, then $C = C*$, and we would have NNP$= C + g(X, 0) - C - z(0) = C + I = g(X, 0)$, or total production. This is the conventional NNP defined as consumption plus net investment evaluated at market prices. However, if pollution were greater than zero, the above equation suggests that the net national product should be calculated as NNP$= \Delta C + g(X, P) - C - z(W)$, which would mean relatively higher consumption $(\Delta > 1)$ and lower net investment (when P,W> 0, g$(\cdot)$ decreases and z$(\cdot)$ increases) compared to the case of no pollution. Consumption-investment ratio is different because the use of the resource base is one type of consumption.

It is in order to emphasize that we are still in a first best world where pollution is chosen optimally by a social planner. However, in equation (7) the correction factor Δ relates pollution to desirable output. Environmental degradation takes the form investment in reproducible capital foregone (cf. Hartwick, p. 297), but *also* appears as a physical output. Our theoretical model has hence a structure which is directly applicable in empirical green accounting work; environmental data are based on registering material flows, and pollution is often measured by linking it to desirable output with certain coefficients. We will return to this point when we discuss the implementation of corrected accounts and the measurement of the correction factor Δ in practice. It will turn out that the factor Δ captures information which can be used in analyses on the enviromental efficiency of the economy and over time and across different sectors.

We can illustrate the NNP measure graphically using production possibilities frontier (cf. Weitzman (1976)). In Figure 1, consumption (C) is indicated on the vertical axis and investment $(\dot{X})$ on the horizontal. The set of production possibilities is depicted as A_oA for an economy which does not pollute $(\alpha = \beta = 0)$. If pollution *is* generated $(\alpha \neq 0, \beta \neq 0)$, the production of goods also inevitably generates undesirable output as a by-product, i.e., $(z_W\alpha - g_P\beta) \cdot C$, whereby, the production possibilities frontier for desirable consumption rotates downward along the vertical axis. At a given level of consumption (e.g., C_o on the vertical axis) less is left for investment due to consumption of resource base $(\dot{X}_1 < \dot{X}_o)$.

In other words, due to consumption of environmental resources in the form of pollution, consumption of desirable outputs per investment, e.g., $\dot{X}_o$ on the horizontal axis becomes more costly and less can be consumed ($C_1 < C_o$). Consequently, in the case of pollution, as shown in the derivations of Figure 1, the maximum income attainable becomes NNP/Δ, given the 'ideal' prices (or slope $-1/\Delta$). Now NNP/Δ is what we call an 'ideal' green NNP, or GNNP; this is what we should measure when including environmental factors in national income accounting.

The intuition is that, due to pollution, environmentally ideal prices differ from market prices which reflect the efficiency of production of the desirable products. If the environmental friendliness of goods is not taken into account, final goods are traded using the environmentally biased market prices. In Figure 2 we observe the market equilibrium as a tangency point $(C^*{}_{obs}, \dot{X}^*_{obs})$ between the desirable production frontier (A_1A) and the broken line reflecting the market prices with slope -1. Consequently, the way the corresponding NNP is currently measured exaggerates future consumption possibilities, or income. Instead, if we apply the correction factor Δ as suggested by equation (7), we obtain a GNNP (NNP/Δ) measure, which is marked on the vertical axis and which is lower than the NNP when $\Delta > 1$.

Another interesting point is that if we took the observed consumption-investment basket $(C^*, \dot{X}^*)$ as given, but used 'ideal prices' corresponding to slope $-1/\Delta$ to correct for accounting prices, we might underestimate the GNNP measure. This is illustrated in Figure 3, where C is evaluated using ideal prices. As can be read from the vertical axis, what we obtain is an incorrect welfare measure NNP' (<GNNP=NNP/Δ). In other words, correcting only afterwards the market prices to account for shadow costs caused by pollution would yield a misleading indicator of welfare, since the *choice of consumption basket is not* a result of an optimization *under correct shadow prices*. This result is also intuitively appealing: green taxes as environmental shadow prices are promoted by needs to correct production-consumption patterns, i.e., the environmental quality of output.

One should also be careful to distinguish the welfare effects of environmental deterioration. There are the direct effects resulting from a utility decrease through preferences, the value of which effects could be captured by willingness-to-pay information included in a green NNP. It is a result of the modelling practices adopted in the literature to date that mainly the direct utility effects have been discussed in the context of green accounting. However, physical pollution effects of consuming the natural resource base affect the productivity of natural capital and should be recognized as they are inherent part of production or, ultimately, consumption. It is important that these two types of impacts not be confounded when interpreting the welfare measures of extended green accounts. If the shadow value of pollution is determined by preferences that are distinguished from consumption choices, the result would be a 'corrected' but misleading measure of welfare of the type NNP'.

Another problem is that using green taxes only for calculating a green welfare measure without actually imposing the taxes, we get a measure which is actually a lower bound of a green NNP. In other words, a green NNP such as indicated in equation (7) gives a picture of the environmental state of an economy only if externalities are fully internalized from that point of time onwards. But it cannot say anything about how far from a first best environmental optimum the economy actually is or will be, if optimal taxes are not imposed and there are no incentives to adjust consumption-production choices accordingly. An additional well-known problem is that the practical implementation of optimal green taxes is not an easy task either.

The above observations cast a serious doubt on a practical relevance of a theoretically consistent green measure of welfare. A green NNP was initially meant for providing information about how well the economy performs from an environmental point of view when it is not in an optimum and how the economic and environmental policy adopted (green taxes, regulations) affect sustainability over time. To study these questions, one needs to move a step forward from the Hamiltonian based optimum approach.

One way to proceed is to use macroeconomic models as suggested, e.g., by Aaheim and Nyborg (1995).[4] For example, dynamic CGE-models can be used for policy analysis to simulate the development of important environmental variables over time. Another approach is promoted here: efficiency indexes. The environmental efficiency indexes can give both a cross section and dynamic picture of environmental performance of economic sectors. Comparisons can be made with a given best available technology reference level; this reference level could be the first best solution presented here.

[4] Aaheim and Nyborg criticize the Hamiltonian approach because of the sensitivity of the green NNP measure for assumptions made; see also, e.g., Brekke (1994).

But before discussing the practical implications of our modelling approach we separate in our second model different types of capital into man-made and natural capital to show that our results do not depend on the broad interpretation of capital stock. The model makes the substitutability between man-made and natural capital more explicit.

3 Model II

We now distinguish two types of capital stock and introduce abatement, a, as a positive input in the production function, g. Hence, we maximize $\int_0^\infty U(C)e^{-\delta t}dt$ subject to

$$\begin{aligned} \text{natural capital} \quad \dot{X} &= g(X, P, a) - z(W) && (8) \\ \text{and manufactured capital} \quad \dot{K} &= f(K) - C - a. && (9) \end{aligned}$$

Again, $P = \beta C$ and $W = \alpha C$, and a is to be interpreted as "man-made abatement" which neutralizes pollution effects on the growth, or the regeneration ability, of the natural capital stock, e.g., fertilizers, lime.

Denoting the shadow price of natural capital and manufactured capital with φ and λ, respectively, the current value Hamiltonian and the necessary conditions are

$$\begin{aligned} \mathcal{H} &= U(C) + \varphi(g(X, \beta C, a) - z(\alpha C)) + \lambda(f(K) - C - a) && (10) \\ \partial\mathcal{H}/\partial C &= U_C + \varphi g_P \beta - \varphi z_W \alpha - \lambda = 0 && (11) \\ \partial\mathcal{H}/\partial a &= \varphi g_a - \lambda = 0 && (12) \\ \dot{X} &= g - z && (13) \\ \dot{\varphi} &= \varphi(\delta - g_X) && (14) \\ \dot{K} &= f - C - a && (15) \\ \dot{\lambda} &= \lambda(\delta - f_K). && (16) \end{aligned}$$

From equations (11)-(12) we have

$$U_C = \lambda + \varphi(z_W \alpha - g_P \beta) \qquad \text{and} \qquad \frac{\varphi}{\lambda} = \frac{1}{g_a}$$

The linearized Hamiltonian is

$$\mathcal{H} = U_C \cdot C + \varphi(g - z) + \lambda(f - C - a) \tag{17}$$

and when divided by the shadow price λ

$$\begin{aligned} \text{NNP} = \quad & [1 + \frac{\varphi}{\lambda}(z_W\alpha - g_P\beta)]C + \frac{\varphi}{\lambda}(g - z) + (f - C - a) \\ & = [1 + \frac{1}{g_a}(z_W\alpha - g_P\beta)]C + \frac{1}{g_a}(g - z) + (f - C - a). \end{aligned} \tag{18}$$

The above equation shows that man-made capital can easily be included as a separate argument in the basic model without changing the term expressing consumption in the form of environmental resources, i.e., $(z_W\alpha - g_P\beta) \cdot C$. An additional insight gained by (18) when compared to (7) is that the relative (shadow) price of natural capital, expressed as $\frac{1}{g_a}$, in fact reflects the degree of substitutability between man-made and natural capital. The higher the marginal product of a in production g, the smaller the adjustment needed for accounting environmental reserves.

4 Implications for measuring a green NNP and implementation of the first best in practice

Recall from equation (7) the expression derived for an optimal green welfare measurement, i.e., NNP= $\Delta C + g(X, P) - C - z(W)$. A first observation is that compared to the conventional measure, i.e., NNP= $C + I$, which neglects pollution impacts, relatively more is consumed ($\Delta > 1$) and less invested ($P, W > 0$). Crucially, the GNNP measure is also a first best solution. In other words, the current consumption basket, C, which we have market data on, would have yielded a first best if people had taken into account the consumption of the natural resource base. If consumers had full information, the accountant's task would be to adjust the conventional NNP given the actual non-market quantitative data on environmental effects (amounts of emissions) per desirable output produced and consumed. To be consistent in our interpretation, consumers' preferences are revealed through actual consumption choices: the smaller the GNNP becomes after adjustments, the more significant the neglect of the environment is in the economy. It is, however, a conscious choice made by economic agents under given technology. This can be seen, for example, from the first order condition (11) which determines the optimal consumption as $U_C = \lambda + \varphi(\cdot)$. Even if the shadow price of natural capital, φ, were high, i.e., natural and manufactured capital were weakly substitutable, consumers would be willing to trade off the state of the environment if the preferences, $U(C)$, reflected high utility from material consumption irrespective of environmental deterioration.

The principal advantage of modelling pollution as an inherent part of production and, ultimately, consumption is that adjustments needed for green accounting can be made using environmental efficiency indexes. An environmental effficiency index takes account of the environmental effects of produced and consumed goods using the best available technology at a given time as a point of reference. Indexes eliminate the problems of estimating shadow prices for negative externalities generated in production and consumption.[5]

We do not need to go into the details of productivity measurement to illustrate the applicability of efficiency indexes as indicators of the environmental performance of production technologies.[6] The basic idea is that output can be divided into goods and bads, which we denote C and $C_{PW} = (z_W\alpha - g_P\beta) \cdot C$ respectively, the subscript PW referring to pollution and waste. Proceeding along the lines of Tyteca (1996), we can, for example, derive an environmental performance indicator as a ratio of two productivity indexes: a net productivity index (NPI) and a gross productivity index (GPI). GPI refers to the more traditional way of measuring output, i.e., excluding undesirable output, whereas NPI takes into account negative by-products. Notationally, GPI=GPI($C \mid l$) and NPI=NPI($C, C_{PW} \mid l$), where C and C_{PW} are the outputs and l refers to the inputs used in the production. The better the productivity, the higher the values that both indexes receive. However, since the GPI does not take account of undesirable outputs, it is likely to be larger than the NPI, if production is not 'pollution-effective', that is, pollutes heavily.

Let us denote the ratio of the above indexes by ϵ =GPI/NPI. In light of the discussion above, for pollution-effective production the index ϵ would be close to 1, whereas increased pollution would result in values of ϵ greater than 1. We can readily contrast the index with our model parameters and notation, i.e., $\Delta = C^*/C$. Recall that $C^* = (1 + z_W\alpha - g_P\beta) \cdot C$.

[5] One of the most recent references on environmental efficiency indexes is Chung et al. (1997).

[6] For a discussion of a variety of productivity indexes that are applicable as environmental indicators see, e.g., Tyteca (1996).

Then, to translate the logic into our modelling terminology, the greater the pollution impact parameters α and β are, the less environmentally efficient production is.

Recall now that an ideal green NNP is the measure NNP/Δ, as shown in Figure 1. Using the indexes Δ from estimations of the environmental efficiency of production, we can adjust the NNP accordingly. With the requisite data available, the adjustments could be made at the industry level and the environmental impacts of outputs of firms within the same sector compared. At a more aggregate level, comparisons of environmental performance could be made between different industrial sectors (see, e.g., Nestor and Pasurka (1993)). Whatever the level of aggregation, the environmentally best available technology determines the point of reference against which adjustments using technology parameters should be made.

It should be noted, however, that in our approach a green NNP becomes a measure the value of which depends on the existence of an efficient production frontier. In addition, a green NNP, defined as a present value of future utility, should be a forward-looking measure of income. We should thus also take into account the technological progress that affects productivity development in the future. While it is clear that these considerations are not necessarily easy to take into account in practice, a welfare index constructed along the lines suggested here (given the best available technology at a given time) would signal how well technological progress in environmental efficiency has spread among different industries. Since it is likely that improved technologies in the future will tend to be less polluting, i.e., the environmentally efficient frontier will be pushed further away from the current frontier, our welfare indicator would approximate the upper bound for a green NNP given the current production structure. For approximating a lower bound, we could make predictions on the development of technology and the corresponding shifts in production frontiers.

Finally, we need to discuss the relevance of accounting a green NNP, or GNNP, when it constitutes a first best solution in the sense that the trade-off between 'material' consumption and pollution is clear to the economic agents. In other words, consumers and producers have full information about the environmental effects of their economic choices and the resulting state of the environment is socially optimal. This assumption can admittedly be questioned, but it does not undermine the implications of our measurement approach. Consumers do not necessarily know the true values of α and β, but when the accountant has access to quantitative data on pollution, the *best available clean technology frontier*, corresponding to output C*, can be estimated to arrive at the correction factor Δ. The correction factor reveals pollution-inefficiency, or the extent to which environmental resources are wasted. An adjusted welfare measure, GNNP= NNP/Δ, gives then an estimate of the present value of future utility when correcting for deviations from an optimum which could be reached using environmentally best technologies that are currently available. The adjusted account can also be compared to conventionally measured NNP, which neglects pollution impacts (or assumes $\alpha = \beta = 0$). If the gap between the GNNP and the conventional NNP is high, the economy evidently has non-market effects on natural resources but is still the first best choice given the preferences of society. However, if, for example, the GNNP turned out to be lower than NNP because of negative environmental impacts *and if* this information as such affected production and consumption choices, it would signal that at least some of the environmental effects were truly external and in fact unwanted by consumers. Actually, the GNNP could then provide information for a learning process: consumers' implicit preferences would in fact be made explicit to them.

It is very likely that, due to incomplete information, the observed consumption basket of desirable output does not represent first best choice. Market-based instruments, i.e., taxes, emission permits (marketed quotas), could then be used to impose the first best solution. A theoretical derivation for implementation of the first best using optimal taxes on undesirable output (or consumption) is relatively straightforward.[7] In practice, however, optimal taxes should be based on the information on ecological, or pollution impacts, which the environmental authorities in part would determine according to the measurable emissions (z_W and g_P) and pollution intensity (α, β) of the output.[8]

As noted earlier, taxes are appropriate corrective measures when they are truly imposed to internalize externalities causing inefficiency in the economy. If taxes are only used as shadow prices for accounting purposes to gain information on the state of the

[7] Derivation of optimal taxes for Model I is shown in Appendix. Of course, given the extensive literature on optimal environmental taxes, there are many complications that make studying green taxes in a purely theoretical framework interesting as such. This is not in our interest here, though.

[8] In fact, if the information required for imposing optimal taxes were available, direct pollution quotas corresponding to appropriate α and β could alternatively be used.

welfare of the environment, there is a risk of making a measurement error we illustrated in Figure 3. In other words, the consumption basket, too, would be different when taxes are imposed. Another, more practical question is what the green taxes collected would be used for. To be consistent with the analysis, green taxes should be subtracted from the NNP to reflect the social cost of pollution. However, taxes are often allocated further to finance government spending which, of course, has different kinds of welfare effects. Due to the various complications related to green (or ecological) taxes in practical accounting work, we suggest, instead, that environmental efficiency indexes of firms or industries could be used to evaluate the welfare impacts of pollution on an economy.

To conclude, it is in order to emphasize the difference of our logic compared to the conventional way of thinking of consumer behavior. On the one extreme, our interpretation for deriving a green NNP is based on the idea of fully informed consumers making consumption choices; the accountant (social planner) only needs to make the numerical adjustments for a correct welfare measure using data on emissions. On the other extreme, the relatively standard assumption made in the optimal control model literature is that consumers are unconcerned or unaware of the environmental effects involved when they make consumption choices, and optimal taxes (based on full information) are needed for internalizing externalities. In reality, the truth about consumer behavior is probably somewhere in between. Everyday consumption choices may occasionally be made with environmental considerations in mind, but even the most socially aware consumer groups may experience difficulties in finding all the necessary information on the environmental impacts of their consumption patterns. Of course, consumer driven green behavior affects producers' choices. There is also recent empirical evidence supporting the hypothesis that environmental externalities are voluntarily internalized by firms.[9]

5 Conclusions

In the previous literature, the growth models used to derive green welfare measures theoretically have implicitly separated the valuation of environmental deterioration from consumption choices. In addition, since the shadow prices of pollution are difficult to calculate, it has become a common practice to use observed prices and quantities as mea-

[9]See, e.g., Arora and Cason (1996) and the references therein.

sures of changes in environmental stocks in green NNP measures. This has been justified by an assumption that market prices probably do not deviate too much from 'ideal' ones.

We have proposed a different point of view for welfare measurement and pointed out the benefits to be gained from recent findings in productivity measurement. Instead of guessing people's preferences, we should probably look more carefully at current consumption choices and production technologies. What we can do is to measure the amounts of undesirable outputs even though we do not know their correct shadow prices. Using efficiency measurement, we can determine the weights to be used in green NNP calculations for taking into account the environmental effects of production and consumption.

We are very aware of the problems of data availability and measurement that we encounter also in environmental efficiency approximations. However, our purpose has been to shift the focus from non-existent shadow price data to the quantitative data on undesirable outputs. By considering pollution as an undesirable output, or source of inefficiency in an economy, we take into account the effects of consuming the natural resource base on the productivity of natural capital – regardless of whether we realize that there is a price to be paid for it or not.

Figure 1: Illustration of the green NNP measure.

$$\text{NNP} = \underbrace{(1 + z_W\alpha - g_P\beta)}_{=\Delta} \cdot C + g(X, P) - C - z(W)$$

Consider now two cases:
1) No pollution: α, $\beta = 0$

then $NNP = C + \underbrace{g(\cdot) - C}_{I} = C + I$ or C= NNP−I

if all output is ultimately consumed, then $I = 0$ and maximum consumption (to be read on the vertical axis) is C=NNP

→ green NNP coincides with NNP

2) Pollution: $\alpha, \beta \neq 0$

then $NNP = \Delta C + \underbrace{g(\cdot) - C - z(\cdot)}_{I'}$ or C= $\frac{NNP}{\Delta} - \frac{1}{\Delta}I'$

if all output is ultimately consumed, then $I' = 0$ and maximum consumption (to be read on the vertical axis) is C=NNP/Δ

→ green NNP (GNNP) is smaller than NNP (since $\Delta > 1$)

Figure 2: The measurement of NNP when pollution consumes the resource base and market prices and ideal prices differ.

NNP = currently measured NNP corresponding to market prices (slope -1)
GNNP = green, or ‘ideal’ NNP corresponding to ‘ideal’ prices (slope $-1/\Delta$)

Figure 3: Underestimation of adjusted NNP: Green NNP (GNNP) compared to consumption evaluated using ideal prices without correcting consumption basket choices (NNP').

Appendix

Derivation of optimal taxes $\tau_\alpha(t)$ and $\tau_\beta(t)$.

If pollution impacts are not at all considered in consumption choices, they can be internalized by using taxes.

•Consumers maximize utility from consumption:

$$\max_{c(t)} \int_0^\infty U(c(t))e^{-\delta t}dt \tag{A1}$$

subject to the capital stock equation

$$\dot{x} = \Pi(t) + r(t)x(t) - c(t) - \tau_\alpha(t)\underbrace{\alpha c(t)}_{W} - \tau_\beta(t)\underbrace{\beta c(t)}_{P} \tag{A2}$$

where $\Pi(t)$ is income to households from firm profits and $r(t)$ is market interest rate on renting capital.

$$\text{f.}o.c. \qquad U_c(c(t)) - \lambda(t)(1 + \tau_\alpha(t)\alpha + \tau_\beta(t)\beta) = 0 \tag{A3}$$

$$\dot{\lambda(t)} = \lambda(t)(\delta - r(t)) \tag{A4}$$

•Firms maximize profits:

$$\max_{x(t)} \; \Pi(t) = g(x(t)) - r(t)x(t) \tag{A5}$$

$$\text{f.}o.c. \qquad g_x(x(t)) - r(t) = 0 \tag{A6}$$

Using equations (A5)-(A6) for (A1) and (A3), the optimization problem (A1)-(A4) now corresponds to the Hamiltonian given in (3) with the first order conditions (4)-(6), if taxes are chosen optimally such that

$$\tau_\alpha(t) = z_W, \quad \tau_\beta(t) = -g_P \tag{A7}$$

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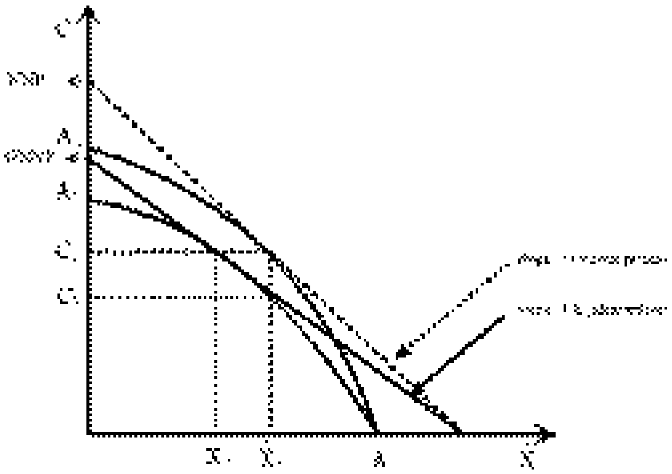

FIGURE 1a

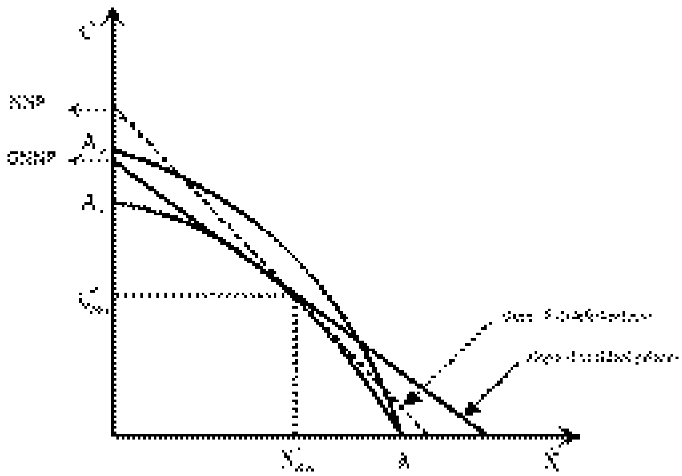

FIGURE 1b

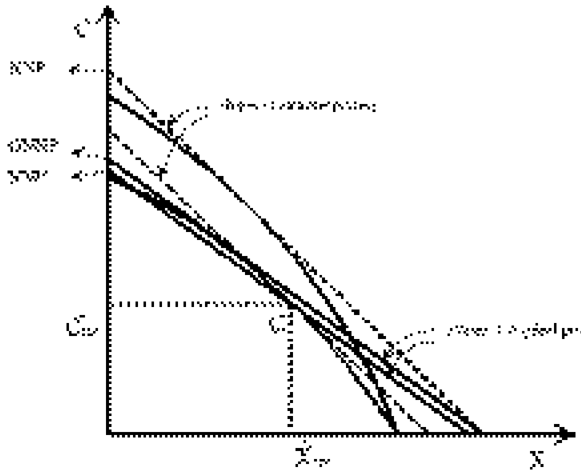

FIGURE 1c