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# CORRECTING NDP FOR $SO_2$ AND $NO_x$ EMISSIONS: IMPLEMENTATION OF A THEORETICAL MODEL IN PRACTICE*

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The theoretical and the practical studies in the field of environmental accounting are often two separate lines of work. In this study, we develop an optimal control theory model for adjusting NDP for the effects of $SO_2$ and $NO_x$ emissions, and subsequently insert empirically estimated values. The model includes correction entries for the effects on welfare, real capital, health and the quality and quantity of renewable natural resources. In the empirical valuation study, production losses were estimated with dose-response functions. Recreational and other welfare values were estimated by the contingent valuation (CV) method. Effects on capital depreciation are also included. For comparison, abatement costs and environmental protection expenditures for reducing sulfur and nitrogen emissions were estimated. The theoretical model was then utilized to calculate the adjustment to NDP in a consistent manner. The estimated damage value of sulfur is close to the Swedish sulfur tax.

## 1. INTRODUCTION

The interpretation of the concept of national income and various ways of adjusting it have been discussed for a long time. In an article from 1939, Hicks analyzed the notion of income, defining it to be net return of the stock (Hicks, 1939). This theoretical framework, defining a perpetually sustainable income, was used for analyses of sustainable development. First formalized by Weitzman (1976), the idea of the national income concept interpreted as the Hicksian definition of income was further developed by, for example, Solow (1986), Hartwick (1990) and Asheim (1994). Mäler (1991) and Dasgupta (1993) focus on the welfare interpretation of the national income concept, and extend this welfare measure to include welfare emanating from the environment. Most of the analyses concern natural resources, with less focus on environmental assets. Explicit treatment of environmental assets can be found in, for example, the work of Mäler (1991) and Hartwick (1990).

The empirical work on green accounting is somewhat separated from the theoretical work in the field. Though the theoretical literature on the issue of green Net Domestic Product (NDP) is quite extensive, few papers deal with the question

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of how to calculate a green NDP in practice. At the same time, many empirical studies have been carried through, both in industrialized and developing countries. The approach is generally very pragmatic and takes the data availability as a starting point rather than the theoretically ideal NDP measure.

During the late 1980s and beginning of the 1990s, case studies were made for a number of developing countries by institutes such as the World Resources Institute and the World Bank (see, e.g. Repetto *et al.*, 1989; Munasinghe and Cruz, 1995). A number of statistical offices in industrialized countries also began compiling environmental national accounts as early as in the 1970s and the 1980s. Norway, Germany and the Netherlands were among the early starters.

This paper aims at linking empirical estimations of a partially environment-adjusted NDP to a theoretical framework. In the paper I use data compiled in a project at the Swedish National Institute of Economic Research (NIER) that I participated in, where efforts were made to compile the data available on the damages from sulfur and nitrogen. By developing a theoretical model I try to bridge the gap between theory and practice by providing a consistent foundation for the compilation of a "nitrogen and sulfur adjusted NDP."

The different valuation methods used in the empirical study follows the SEEA (System of integrated Environmental and Economic Accounts) 1993 draft handbook, supplemented by a *valuation* of production losses, estimated using dose-response functions. The methods discussed in the paper only concern the flows and the stock changes during one year. The paper thus does not deal with total accumulated damage over the years, i.e. the state of the environment, but only with the changes in the state of the environment due to society´s acitivities during a certain year.

## 2. VALUATION OF DAMAGES

In the empirical valuation studies, the effects of sulfur and nitrogen emissions on welfare, real capital and the quality and quantity of renewable resources are included. The damages are mainly stock effects, but some damages are due to the flow of emissions (health effects and corrosion). Depletion of exhaustible resources or degradation of renewable resources due to other causes (e.g. land use) is not included.

The effects included in the empirical study are:

- Depreciation of real capital: corrosion.
- Depreciation of natural capital: fish stock, forest stock, water (lakes and sea).
- Depreciation of labor stock: health effects.

This results in loss of:

- Marketed products: fish, timber, corrosive materials, working hours.
- Non-marketed products: fish.
- Recreational values from forests, lakes and sea.

The effects are thus both through reduced flows and reduced quality of stocks. Corrosion and health effects are due to the current flow of pollutants; the other effects are due to the size of the stock of pollutants in the ecosystems.

TABLE 1

Components in the Valuation Study and Corresponding Variables in the Model (in Utility Terms)

| | | | |
|---|---|---|---|
| Environmental protection expenditures | Liming, sewage water treatment | $\lambda_K f(b)$ | Cost estimation |
| | Health care costs, catalytic converters | $\lambda_C$ times part of $C$ | Cost estimation |
| | Corrosion | $\lambda_K$, $\lambda_C$ times part of $F$ and $C$ | Dose-response function |
| Changes in market value | Nitrate in groundwater | $\lambda_K k(E)$ | Cost estimation |
| | Corrosion | $\lambda_K k(E)$ | Dose-response function |
| Production losses | Timber growth | $\lambda_S g_x dX/dt$ | Dose-response function |
| | Fish stock | $\lambda_s g_x dX/dt$ | Dose-response function |
| | Labor supply (health) | $\lambda_L l(E)$ | Dose-response function |
| | Crop damages | Lower $F$ | Dose-response function |
| Welfare effects | Health | $U_E E$ | CV study |
| | Recreation, groundwater quality | $U_x X$, $U_x dX/dt$ | CV study |

In Table 1, the components included in our study are listed. The first column shows the kind of effects, the second column shows the affected items included in the empirical study, the third column shows the corresponding variables in the theoretical model (to be defined below) and the fourth column shows which method was used to estimate the prices.

All the components relate to emissions and effects of different forms of nitrogen (both to air and water) and sulfur dioxide (NIER, 1998). The environmental protection expenditures, which are a disaggregation of the conventional accounts, include costs of liming, catalytic converters, health care, corrosion and sewage treatment plants. The wealth effects consist of depreciation of real estate due to high nitrate levels in groundwater and of depreciation of real capital due to corrosion. The production losses are estimates of reduced timber growth due to acidification, loss of fish catches due to eutrofication and acidification, crop losses due to ozone and sick-leaves due to high ambient concentration of nitrogen oxides. Welfare effects were estimated through a contingent valuation study, which included questions about the respondents' willingness to pay for avoiding damages from acidification, eutrofication, nitrate in groundwater and air pollution (nitrogen oxides).

Below a short overview of the empirical valuations is given. For a more extensive description, see NIER (1998). The methods chosen in the study are the ones included in the 1993 SEEA together with estimation of production losses using dose-response functions; the latter being the method most compatible with economic theory. The valuations are done using the best available data. In some cases new data were estimated and one survey was undertaken. A considerable amount of time and money went into estimating the values shown here. However, given the scarcity of readibly available data, the estimates are incomplete and should be regarded as tentative. The main point of this study is to try to link theory and empirical estimations, and to point to a way forward that could hopefully be useful for future work in this area.

The data on costs and damages have been compiled by several persons, and are the result of a thorough inventory of data and surveys available (see NIER, 1998 and annexes). Aggregation of the data follows the SEEA interim handbook and aims to provide an overview of the different valuation methods and their implications. The analysis also provides information on currently available knowledge about the economic implications of sulfur and nitrogen emissions.

Effects on market goods, such as timber, are valued with market prices. If timber cutting affects the recreational or non-use values of the forest, this would show in the welfare effects of stock changes (this effect is however not included in the empirical study). The impacts on environmental goods are valued both with market prices of similar goods and with willingness-to-pay (WTP) estimates. As an example, the households' harvests of fish are diminished as the stocks of nitrogen and sulfur increase. The estimated catch loss is valued by market prices of fish, while decreased welfare due to lower quality of the fishing waters is captured by WTP estimates.

We also tried to detect possible decreases in wealth due to acidification and eutrofication. Both the wealth estimations and the environmental protection expenditure accounts are disaggregation of the ordinary asset and production accounts.

*Environmental protection expenditures*: The environmental protection costs are calculated on the basis of pilot studies carried out at Statistics Sweden and the NIER. The liming figures for fresh water and forest soil are total liming costs for 1991. These costs are borne by the State. The liming figure for agricultural soil is calculated on the basis of farmers' expenditures on lime in 1991, and on the estimation made by the Swedish University of Agricultural Sciences that 20 percent of the liming requirement is attributable to emissions of sulfur into the air. The costs of catalytic converters are calculated from cost information relating to various makes and models of cars. Health care costs comprise additional costs of medicines and care costs in respect of health problems that are related to increased contents of $NO_2$ (Hahn, 1996). Correspondingly, the corrosion cost is the additional cost incurred for protecting/repairing real capital (buildings, vehicles, infrastructure, water main systems and protection of historical values).

*Changes in market value of stocks*: Nitrate in private wells should be expected to reduce the value of the properties by the cost of installing a purification system with filters connected to the well. The possibility of doing a hedonic pricing study was examined, but there was not enough data to perform such a study. Instead, the capital depreciation was estimated by the cost to install filters to reduce the nitrate content.

The estimates of accelerated corrosion of capital cover buildings, vehicles, infrastructure, water main systems and protection of historical values. They are done by using data and dose-response functions from the Swedish Corrosion Institute, but also from other sources such as research reports. Where such information has not been found, ad hoc data have been gathered (Andersson, 1994; NIER, 1998).

*Production losses*: The production boundary is expanded to include nature's production of all kinds of herbs, animals and ecosystems. Many of the biological effects are well known but are difficult to quantify. We have quantified damages related to timber, crops, human health, fish and shellfish. The productivity reduction in forests owing to acidification is the damage that occurs as a result of sulfur emission in 1991, under the assumption that the emissions decrease according to the Geneva protocols (see NIER (1998, section 3.1) and Skånberg (1998)). The reduction is calculated with a dose-response function that specifies how the deposition of sulfur dioxide and nitrogen oxides affects the soil chemistry, and how this in turn affects the growth rate of spruce and pine.[1] The loss is valued at market price (stumpage prices).

The fish losses are calculated as if the loss of fish catches were proportional to the estimated loss of fish stocks due to acidification and eutrofication. It should be noted that the loss of fish is quantified for different kinds of fish, which is important since the fish that are most sensitive to pollution often are the best quality fishes, like char and salmon. The prices used are market prices for the different species.[2]

The health effects are mostly due to ambient concentrations of nitrogen oxides in the larger cities, which causes respiratory diseases. The estimations comprise the loss of output owing to diseases caused by nitrogen per year (Hahn, 1996; NIER, 1998). Of the production losses, 420 million are due to earlier retirement and 230 million due to sick-leave. The estimates are made using a study on the contribution of high $NO_x$ concentrations on respiratory diseases and data on average wages. They comprise the loss of output owing to diseases caused by nitrogen per year.

*Welfare effects*: The NIER carried out a national CV study in 1996, asking how much people were willing to pay in order to avoid the acidification and eutrofication problems at a national level. The respondents were asked how much they would be willing to pay on a yearly basis, given that all people in Sweden would pay the same amount via the tax bill. The five environmental issues they were asked to value were: acidification of lakes and forests; eutrofication of lakes and coastal areas; and increased levels of nitrogen in groundwater. The valuation of health effects was taken from another CV study (Leksell and Löfgren, 1995). The estimated values from the CV studies do not refer to marginal disutility, which would be the desired estimate in the national accounting context, but to average disutility. This issue and how it has been handled in this study is further addressed in Section 4.

Not all of these values are used to correct NDP. Some, like the environmental protection expenditures, are merely disaggregations of the conventional

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[1] Following Sverdrup and Warfvinge (1994). Their results have been used as a basis for the Geneva protocol negotiations. They have however been disputed by other researchers; see e.g. McLaughlin (1985).

[2] Harvesting costs have not been subtracted from the price since the costs for landing the fish do not change regardless of the size of the fish catch (apart from a small change in work time). Thus the loss is equal to the market price times the reduction in fish catch.

national accounts. The theoretical model developed below provides a structure for how the correction should be done.

## 3. A Theoretical Model

In this section I will outline a model for the environmental adjustments made in the empirical study. The aim is to provide a structure for the damage valuations.

There are a number of ways in which a model including environmental effects can be formulated. Hartwick (1990) and Hamilton (1996) develop a series of models for different specifications of effects on environmental resources and welfare from pollution, while Mäler (1991) develops one model including both pollution, abatement, time allocation to different purposes and household production. For recent summaries of the literature, from various perspectives, see Dasgupta and Mäler (2000) and Asheim (forthcoming).

The utility function in such a model often contains benefits from non-market goods and services as well as market consumption. However, as pointed out by Usher (1981), there is no reason to include stocks that are unchanging, as long as we are focusing on intertemporal welfare analysis for a single economy. The issue in focus is the difference between the environmentally adjusted NDP measure (EDP) and conventional NDP, not the absolute level, and thus an addition of the benefits from a non-deteriorated environment is not essential as long as they are constant.

The model outlined below is a standard dynamic optimization model in the same tradition as, for example, Hartwick and Mäler (mentioned above), tailored to describe the environmental topics covered in the empirical work. This means that it portrays a first best situation, and is thus a simplified illustration of the real situation. A market economy solution will coincide with the command optimum solution only if the emission taxes in the economy are dynamic Pigouvian taxes. In the real world, where we have imperfect market economies and non-Pigouvian taxes, the welfare measure will look slightly different, as shown in, for example, Aronsson and Löfgren (1995, 1998). The model below is a cruder approximation, developed to provide a structure for the empirical green GDP estimations.

I specify the utility function as $U(C, \mathbf{E}, \mathbf{X})$ where $C$ = market consumption of an aggregate consumption good, $\mathbf{E}$ is a vector of emissions, $\mathbf{E} = [SO_2, NO_x, NH_3]$ and $\mathbf{X}$ is a vector of the stocks of these three pollutants. Pollution is a "bad," so $U_{Xi}$ and $U_{Ei} < 0$.

The social planner's optimization problem is to choose consumption, $C$, harvest rate of the natural capital stocks, $R$, abatement rate, $b$, and emission rate, $\mathbf{E}$, so as to maximize[3]

$$(1) \qquad \int_t^\infty U(C,\overline{E},\overline{X})e^{-r\tau}d\tau$$

$$(2) \quad \dot{K} = F(K,L,R,E) - C - \sum_j f_j(b_j) - \delta K - \sum_j k_j(E_j), \quad j = \mathrm{SO_2}, \mathrm{NO_x}, \mathrm{NH_3}$$

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[3] Bar denotes vector. Time indices are suppressed to simplify notation.

(3) $$\dot{L} = (n - l(E_{NO_x}))L, \quad n - l(E_{NO_x}) >> 0$$

(4) $$\dot{S}_i = \sum_j g_i(S_i, X_j) - R, i = \text{forest, fish} \quad j = \text{SO}_2, \text{NO}_\text{x}, \text{NH}_3$$

(5) $$\dot{X}_j = (1 - \alpha_j)E_j - b_j + I_j - d_j, \quad j = \text{SO}_2, \text{NO}_\text{x}, \text{NH}_3, \quad 0 \leq \alpha \leq 1$$

where

$U$ = utility function
$F$ = production function
$C$ = consumption
$X$ = pollution stock
$K$ = real capital stock
$L$ = labor stock
$E$ = emission of pollutants (proportional to energy use in the production function)
$S$ = natural resource stock
$R$ = harvest
$f$ = abatement cost function
$b$ = abatement rate
$g$ = growth of stock
$\delta$ = depreciation rate, excluding depreciation due to pollution
$k$ = depreciation of capital due to pollution
$l$ = labor supply effects as a function of pollution
$d$ = dissipation rate (exogenous)
$I$ = import of pollutants (exogenous)
$\alpha$ = part of emissions that is exported
$\tau$ = time

The utility function is strictly concave, increasing in consumption *C* and decreasing in **E** and **X**. The growth equations for the stocks are assumed to be concave.

Production is a function of labor *L* and capital *K*, of the harvesting of natural resources *R* and emissions/energy *E*. The production function is assumed strictly concave and increasing in all variables. To simplify the model, I assume that the emission rates are fixed and that emissions are equal to energy use. Thus the variable *E* can be interpreted in the production function either as energy use or as (a positive) "input" of emissions. I will suppress the fact that emissions are also generated in the consumption phase, and assume that these emissions are accounted for in the production emission rates. The valuation estimates in the empirical study refer to effects from both production and consumption emissions.

Production can be used for consumption of marketed goods and services *C*, abatement of emissions *f*(*b*) and investment. The stock of real capital depreciates by a constant depreciation rate *δ*, and additional depreciation *k*(***E***) that depends on current emissions (here, additional corrosion due to acidification). The change in the stock of real capital (equation 2) is thus net investment. Public consumption is implicitly present in the consumption variable *C*, and so abatement costs *f*(*b*) are actually a separately shown part of *C*. The abatement cost function *f*(*b*) includes only the costs for measures that reduce the stock of pollutants, i.e. it does not include measures that directly reduce emissions given the amount of emissions. For example, it includes costs for liming and sewage water treatment but not costs for catalytic converters, fuel switches and filters that reduce sulfur emissions. Measures for reducing emissions result in a lower level of $E$; the costs for these are included in the costs of production. These could be separately shown, but are part of the conventional NDP. Both $f(b)$ and $k(E)$ are assumed to be concave functions.

The labor supply is affected by pollution in that sick-leaves and early retirements increase due to high ambient concentrations of pollution. Since it is only the environmental effects that interest me here, population growth and other determinants of labor supply are suppressed. Furthermore, the supply of labor is not a decision by the households; i.e. the households do not optimize the allocation of time between labor and leisure. This is because the value of leisure is not central to the study, which focuses on effects from environmental externalities.

As in the case of depreciation of real capital, it is important not to double count effects that reduce the conventional NDP. If the health effects reduce the labor supply in the current period, these changes are already accounted for in the conventional NDP and so should not be deducted. If, on the other hand, the damages affect labor supply in coming periods, an adjustment should be made in the EDP calculations.

The natural resource stocks grow at a normal rate, which is affected by the stock of pollution ($g(S,\mathbf{X})$). The growth function $g$ is non-decreasing in $S$ and non-increasing in $\mathbf{X}$. Damage from pollution is measured as a quantity change of the resource stocks (e.g. slower growth of the timber stock due to accumulation of acidifying substances in the soil). The quality aspects are captured in the utility function of the households. Abatement in this model includes governmental abatement services (liming and sewage treatment).

The stock of pollution, finally, is assumed to increase by the emitted amount of pollutants less the dissipation rate, $d$ (e.g. the buffering ability of forest soil).

The current value Hamiltonian of the optimal growth problem is[4]

$$\begin{aligned} H(t) = U(C,\overline{E},\overline{X}) + \lambda_K[F(K,L,R,E) - C - f(b) - \delta K - k(E)] + \lambda_L[(n - l(E))L] \\ + \lambda_S[g(S,X) - R] + \lambda_X[(1-\alpha)E - b + I - d] \end{aligned}$$

The first order conditions are

$$\frac{\partial H}{\partial C} = 0 \Rightarrow U_C = \lambda_K \tag{6}$$

$$\frac{\partial H}{\partial R} = 0 \Rightarrow \lambda_S = \lambda_K F_R \tag{7}$$

$$\frac{\partial H}{\partial E} = 0 \Rightarrow U_E + (1-\alpha)\lambda_X - \lambda_K(F_E - k_E) - \lambda_L l_E L = 0 \tag{8}$$

$$\frac{\partial H}{\partial b} = 0 \Rightarrow -\lambda_K f_b - \lambda_X = 0 \tag{9}$$

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[4] In the following, I will suppress indices for natural resource stocks and pollutants in order to simplify notation.

The shadow prices of stocks are given by the differential equations

$$\dot{\lambda}_K = r\lambda_K - \frac{\partial H}{\partial K} = \lambda_K (r - F_K + \delta) \tag{10}$$

$$\dot{\lambda}_L = r\lambda_L - \frac{\partial H}{\partial L} = \lambda_L (r - n + l(E)) - \lambda_K F_L \tag{11}$$

$$\dot{\lambda}_S = r\lambda_S - \frac{\partial H}{\partial S} = \lambda_S (r - g_S) \tag{12}$$

$$\dot{\lambda}_X = r\lambda_X - \frac{\partial H}{\partial X} = r\lambda_X - U_X - \lambda_S g_X \tag{13}$$

By the first order conditions, marginal utility of consumption is equal to the price of capital. The differential equation for the shadow price of the real capital stock $K$ implies that in steady state, the marginal productivity of capital should equal the sum of the discount rate, $r$, and the depreciation rate $\delta$.

The shadow price of natural capital is defined similarly to the price of real capital, following an arbitrage condition that says that the price changes when the growth rate of the stock differs from the discount rate. The shadow price of labor, $\lambda_L$, is equal to the discounted present value of the shadow price of capital times marginal productivity.

The (negative) value of pollution, finally, is larger if the effect of pollution on the natural resource growth or on utility increases. If the stock of pollution increases, the (negative) price of pollution also gets larger (i.e. higher in absolute value). That is, the price of pollution increases with the damage of pollution, valued by its effect on the growth of the resource stock and on the utility of households.

The differential equation for the shadow price of pollution implies that

$$\lambda_X = \int_t^{\infty} (U_X + \lambda_S g_X) e^{-r(r-t)} d\tau$$

i.e. the discounted sum of the marginal disutility of pollution and the impaired growth. This equals the sum of the marginal value of the damages to natural resources and households.[5] From the expression for the EDP (environmentally adjusted net domestic product) we thus see that the change in the stock is valued both by its utility for households, $U_x$, and by its effect on production, while the current stock of pollution is only valued by its utility for households.

The linearized Hamiltonian gives the expression for EDP in utility terms:

$$\text{EDP} = U_C C + \lambda_K \dot{K} + \lambda_L \dot{L} + \lambda_S \dot{S} + U_E E + U_X X + \lambda_X \dot{X}$$

The expression may be divided through with $U_c$, to convert into units of the numeraire good. Note that the effects from the current flow of emissions $E$ are different from those from the change in the stock of pollutants $X$. This is because

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[5] Damages from pollution *flows* are not present here, since this is the shadow price of the stock of pollution. They are reflected in the prices of real capital and labor.

the pollutants have multiple effects. In the case of sulfur and nitrogen, they effect health, crops etc. while in (high concentrations in) the air and add to eutrofication and acidification when deposited in water and soil.

The first two terms equal the conventional net national product. The next terms add changes of the labor supply and the natural resource stock. The last three terms are adjustments for marginal values (damages) of pollution. Terms five and six are the (negative) values of the current flow of emissions and of the present stock of pollution, valued at households' marginal valuation. The last term reflects the value of additions to the stock of pollution, which is valued both by its future effects on production and on the current utility of households.

It should be noted that not all of the components in Table 1 are to be deducted from NDP since they are simply an environment-related disaggregation of conventional NDP or estimations of "consumption foregone" (i.e. production of market goods is lower due to pollution). The environmental protection expenditures are all included in conventional NDP; liming and sewage treatments are part of public expenditures. Public expenditures are not explicitly represented but may be viewed as contained in $C$. Environmental protection expenditures reduce the growth of the pollution stock and reduce net investment. Health care and corrosion costs that are part of consumption expenditures are not explicitly shown in the model. Firms' expenditures for treating corrosion are part of investment. The health effects on labor supply in the sulfur-nitrogen study are partly current effects that are included in conventional NDP; earlier retirement and early deaths that decrease future labor supply. The long-term effects are included as a function of emissions $l(E)$.

The expression for EDP shows that in the case of effects of production, only stock changes should be included in the EDP estimate. Current effects are already implicitly included, since NDP has a lower value than it should have had in the absence of environmental effects.[6] The same applies to effects on market consumption. In the case of utility effects, however, both current and future effects should be included.

In a market economy, the stock of pollution is not internalized, and therefore the optimization problem of the economy does not include the adjustments for the effects of pollution shown above. As an approximation of how welfare is actually changing due to our choices, we can estimate the shadow prices according to the theoretical model and add the "missing" terms (i.e. the last four terms in the EDP expression) to conventional NDP.

## 4. CALCULATING AN EDP

In this section I will put together the valuation estimates according to the theoretical model that I outlined in Section 3.

Table 2 gives a summary of the results from the various valuation studies. The sector cost shares have been calculated in proportion to the sector's share in the total load, taking into consideration the higher impact of Swedish emissions in

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[6] In the model I have separated the accelerated depreciation due to pollution from the "normal" depreciation.

TABLE 2

ENVIRONMENTAL ACCOUNTS FOR EMISSIONS OF SULFUR AND NITROGEN FOR 1991

| | Total Deposition in Sweden | Attributed to Swedish Emissions | Percentage of NDP* Total | Percentage of NDP* Swedish Emissions |
|---|---|---|---|---|
| Physical accounts, kton | | | | |
| $SO_2$ | | 115 | | |
| $NO_x$ | 464 | 394 | | |
| $NH_3$ | 788 | 51 | | |
| N to soil and water | | 85 | | |
| Valuation estimates, million US$ | | | | |
| Wealth effects | 127 | 41 | 0.1 | 0.03 |
| Production losses | 241 | 153 | 0.2 | 0.1 |
| Willingness to pay estimates | 2176 | 994 | 1.5 | 0.7 |
| Avoidance costs | | 809 | | 0.6 |
| Environmental protection costs, million US$ | | 294 | | 0.2 |

*Swedish NDP was US$146,588 million in 1991.

some cases (e.g. $NO_x$ concentrations in cities). The estimates of the total costs of the environmental impacts from sulfur and nitrogen in Sweden range between US$367 million and US$2,176 million, i.e. close to 1.5 percent of NDP. The sums in the second column are the ones that should be deducted from value added in the Swedish sectors.

I will now use the theoretical model to identify the requested values.

The linearized current value Hamiltonian for the model is:

$$H(t)=U_C C+U_X X+U_E E+\lambda_K[F(K,L,R,E)-C-f(b)-\delta K-k(E)]$$
$$+\lambda_L[-l(E)]+\lambda_S[g(S,X)-R]+\lambda_X[(1-\alpha)E-b+I-d]$$

The resulting expression for EDP in monetary value can be written as:

$$\mathrm{EDP}=C+\dot{K}+\rho_L\dot{L}+\rho_S\dot{S}+\rho_X\dot{X}+P_E E+P_X X,$$
$$\rho_i=\frac{\lambda_i}{U_C},\quad i=L,S,X$$
$$P_i=\frac{U_i}{U_C},\quad i=E,X$$

The first two terms correspond to the conventional NDP, with a disaggregation for environmental effects. The change in the natural resource stocks in the fourth term includes the stocks of fish and timber. The next term, $\lambda_X X$, adjusts for environmental degradation. The last terms represent the disutility that the households experience due the current flow of emissions and the level of the pollution stock. These are non-market values. Recall that the shadow price of pollution is

$$\lambda_X=\int_t^{\infty}(U_X+\lambda_S g_X)e^{-r(\tau-t)}d\tau$$

Thus environmental degradation is valued by the depreciation of the natural resource stocks and the additional disutility to households due to the change in the pollution stock, i.e. the emissions during the current period. The decrease in the timber and fish stocks due to pollution is thus valued by the market price of these goods times the estimated decrease in growth of the stocks $\lambda_s g_x$. The second term, $U_x$, reflects the households' disutility from pollution, which is approximated by the average willingness to pay (WTP) for a decrease in the pollution stocks. For practical purposes, it is useful to rewrite the EDP expression as

$$\text{EDP} = C + \dot{K} + \rho_L \dot{L} + \rho_S \dot{S} + \rho_S g_X \dot{X} + P_E E + P_X (X + \dot{X})$$

since in CV studies it is not easy to separate the disutility to households due to the current *level* of the pollution stock and to the *change* in the pollution stock. The questions in our study asked for the willingness to pay per year for a reduction of the pollution stock to a level that would not have any negative effects on the state of the environment. Thus the WTP refers to a permanent reduction of the deposition of pollutants to sustainable levels, which includes both a reduction of the existing stock and of future additions to the stock, assuming that the environment will recover if the deposition rates are reduced to sustainable levels. The marginal disutility $P_X$ is approximated with the average value per year and per pollutant. The consumer surplus included in the value for the total reduction of the stock (i.e. the sum over the years the environment needs to recover) is in this way somewhat reduced. The estimated values do not refer to marginal disutility but to average disutility. Thus they are not marginal values as requested, but as pointed out earlier, it was not considered feasible to pose questions on marginal changes. The obtained average values will thus have to serve as an approximation.

The shadow price of capital, $\lambda_K$, is approximated with the market price for capital. The same holds for the shadow price of the natural capital stocks, fish and forest, and for the shadow price of labor, $\lambda_L$ that is approximated with average wages. From the model, we see that in steady state $\lambda_L$ can be written as

$$\lambda_L = \frac{\lambda_K F_L}{r}$$

where $\lambda_K$ is the output price. To get a monetary value all the variables are divided through with $U_C = \lambda_K$, which should also be divided with the discount rate. $\rho_L$ is thus simply approximated with the wage. The same line of argument holds for the shadow price of natural capital $\lambda_S$ and marginal disutility of pollution stocks $U_X$.

Table 3 lists the figures that should be included in an adjustment of NDP. Ignoring the entries that are merely disaggregation of the conventional NDP or "consumption foregone," we obtain a total adjustment for acidification and eutrofication amounting to about US$2,331 million.

A "sulfur-nitrogen adjusted" NDP—here called EDP—can thus be calculated:

$$\text{EDP} = 146588 - 49 + 647 - 105 - 1788 - 388 = 144905 \text{ million US\$}$$
$$(\text{NDP} + \rho_L \dot{L} + \rho_S \dot{S} + \rho_S g_X \dot{X} + P_X (X + \dot{X}) + P_E E)$$

TABLE 3

COMPONENTS OF ADJUSTMENT OF NDP; 1991 PRICE LEVEL

| | Variable | Million US$ | Valuation Method |
|---|---|---|---|
| Timber | $\rho_s g_X\, dX/dt$ | 94 | Dose-response function |
| Fishing, professional | $\rho_s g_X\, dX/dt$ | 11 | Dose-response function |
| Labor supply | $\rho_L\, l(E)$ | 49 | Dose-response function |
| Fishing, households | $P_x(X + dX/dt)$ | 106 | CV study |
| Recreation, Baltic | $P_x(X + dX/dt)$ | 294 | CV study |
| Recreation, Lakes | $P_x(X + dX/dt)$ | 882 | CV study |
| Recreation, Forest | $P_x(X + dX/dt)$ | 271 | CV study |
| Nitrate in groundwater | $P_x(X + dX/dt)$ | 235 | CV study |
| Health | $P_E E$ | 388 | CV study |
| Total adjustment | | 2331 | |

The estimate pertaining to the change in the timber and fish stocks is a rough estimate. The net increase in the timber stock has been valued to US$659 million. Fish stocks decreased in value terms by some US$12 million.

The estimate of EDP presented here is a measure of the *level* of "sustainable income" as in Weitzman's model (Weitzman, 1976, 2000), not of the *change* in welfare as is the primary interest of the authors in Heal and Kriström (1999) or Dasgupta and Mäler (2000). NDP can be interpreted as a measure of the return on national wealth. As environmental externalities are not accounted for, conventional NDP is an overestimate of our wealth, which is also shown by the EDP calculated here.

In total, the sulfur-nitrogen adjustment in our study equals US$2,331 million, which is about 1.6 percent of NDP. This figure is a lower bound estimate since many effects are not quantified (e.g. effects on biodiversity, cultural objects and electrical contact materials). Also, the included estimates throughout are conservative. Excluding the willingness-to-pay values, which, unlike the national accounts include consumers' surplus, the adjustment is reduced to US$154 million. To give some perspective of the order of magnitude, the amount paid for social allowances in Sweden 1991 was US$659 million and for agricultural subsidies was US$376 million. The income from the sulfur tax was US$26 million.

In addition to the values that should be included in the adjustment, several effects from pollution have been found that affect conventional NDP, but are not shown explicitly in the conventional accounts. Though not part of the EDP adjustments, these costs of pollution can be of interest, especially in intertemporal or inter-country comparisons. They represent effects that depreciate economic assets or measures that use means and resources which could have been used for other purposes, had it not been for pollution.

The costs for the relevant part of corrosion amount to US$224 million. These are apportioned equally between depreciation of capital ($k(E)$) and actual costs (belonging to the environmental protection expenditure account, though not included in $f(b)$ since corrosion maintenance does not reduce the pollution stock and the measures included in $f(b)$ are such that reduce the pollution stock). High levels of nitrogen in groundwater reduce the value of real estates by an amount of

12 million, which is also part of $k(E)$, being a part of the capital stock in the housing sector. The costs for catalytic converters and health care costs (US$79 million) are borne by households and the public sector, and are part of consumption expenditures.

The costs of liming and sewage treatment (15 + 85 = US$100 million), are part of public consumption. Liming and health care are restoration measures, while sewage treatment and catalytic converters are avoidance measures. Total environmental protection expenditures and depreciation of real capital that could be allocated to sulfur and nitrogen are 224 + 79 + 100 = US$403 million, or 0.3 percent of NDP. Decrease in working hours due to sick-leave causes a production loss of US$3 million. Damages to crops amount to US$7 million.[7] These two effects represent consumption foregone, and could be added to conventional NDP to show "potential NDP."

## 5. Concluding Comments

In accounting, it is important to avoid double-counting and other inconsistencies. A theoretical model, even if simplified as in the present paper, provides a coherent framework for empirical estimations. In the SEEA, various valuation methods are kept apart in order not to mix values with different scope. However, the different valuation methods can be complementary to each other. If only one method is used at a time, the EDP measure will be more fragmentary than if a mixture of methods can be used in a consistent manner. The theoretical framework used here is, however, not sufficient to ascertain consistency since some of the problems that arise are due to the empirical estimation methods.

One such problem is that the estimation of production and welfare losses in this study is different due to the different properties of the valuation methods. The production loss estimation includes only market prices, which are marginal values, whereas WTP estimates of the welfare losses often are not marginal and include consumer surplus. If we seek a linear welfare measure, consumer surplus should not be included. In the CV study of the NIER we tried to reduce this problem as discussed in the previous section.

Different methods produce estimates that are very different in magnitude. This is hardly surprising since the scope of the methods is very different. In CV studies, the goods and services that are actually valued are often not explicitly specified but concern values of more general benefits from different ecosystems, values of having good health, etc. Questions that are specific enough to relate the answers to specific pressures are, in general, difficult to answer. Thus a more encompassing, but less detailed picture is given than when estimating production losses (even if a wider approach is used for the production losses than in this study).

In addition to the differences in scope regarding economic loss and welfare, the time and space addressed also differ. The production loss calculations refer to future effects from today's emissions (this is the approach that is closest to the theoretical models). The CV estimates concern, for reasons mentioned above,

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[7] The total value of the crop damages due to tropospherical ozone is 118 million US$ per year (Pleijel *et al.*, 1990).

reduction of the current pollution stock, and thus in general they are not explicitly linked to current emissions or future damages.

How about the often-discussed issues of weak sustainability and discontinuities—were they crucial in the empirical estimations? In the production loss calculations for acidification, the impact of current emissions on future production are estimated for a rather long time interval in certain cases. Since the calculations are discrete, and the stock of pollution is calculated for each year, it is possible to see whether threshold effects or irreversible changes will occur. If the assumption is correct that acidification of the soil is a reversible process given that the pH value does not get very low, no irreversible effects will occur in the presumed scenarios. The question of strong versus weak sustainability is mostly an issue in the case of irreversible changes, and since no such changes have been envisaged, the problem was not thought to be significant in these calculations.

For the other environmental effects, the valuations are based on the assumption that the magnitude of the effects will be within a range where damages depend linearly on the deposition of pollutants. If the damages worsen significantly, or if threshold effects occur, the valuations are underestimations. If the damages are irreversible, the weak sustainability assumption will be of crucial importance.

In conclusion, the theoretical model has provided information on which values should be sought for when doing empirical estimations. Since in this study the theoretical model was constructed after the empirical study was completed, the framework provided by the model supported the sorting out of which values should be included and how they could be combined. Constructing the model has also helped structuring the different damage effects.

The empirical results are useful for several purposes. As exemplified in the previous section, they can serve as a foundation for discussions of environmental taxes and provide justification for tax levels, and can be used for discussing priority matters. The integration of statistics into one coherent system has many advantages. Integrated economic and environmental accounts provide a possibility to estimate environmental consequences of economic scenarios or policies, and to investigate economic implications of environmental policies, as well as cost-effective ways of implementing environmental policies. They make it feasible to show the interaction of economic activities, linked to the effects on the environment, and to estimate how other environmental variables are affected by a policy aimed at, for example, one specific emission.

## REFERENCES

Andersson, Björn, *Korrosionskostnaden orsakad av SO2-emissioner* (The corrosion costs caused by $SO_2$ emissions), NIER, 1994.

Aronsson, Thomas and Karl-Gustav Löfgren, "National Product Related Welfare Measurement in the Presence of Technological Change, Externalities and Uncertainty," *Environmental and Resource Economics*, 5, 321–32, 1995.

———, "Green Accounting in Imperfect Market Economies," *Environmental and Resource Economics*, 11(3–4), 273–87, 1998.

Asheim, Geir, "Net national product as an indicator of sustainability," *Scandinavian Journal of Economics*, 96(2), 257–65, 1994.

———, "Green National Accounting for Welfare and Sustainability: A Taxonomy of Assumptions and Results", *Scottish Journal of Political Economy* (forthcoming).

Dasgupta, Partha, "Optimal Development and the Idea of Net National Product," in I. Goldin and L. A. Winters (eds), *Approaches to Sustainable Economic Development*, Cambridge University Press for the OECD, Paris, 111–43, 1993.

Dasgupta P. S. and K-G. Mäler, "*Net National Product, Wealth and Social Well-being*," *Environment and Development Economics*, 5(1–2), pp. 69–93, 2000.

Hahn, Gunnela, *Samhällsekonomisk värdering av kväveoxidrelaterade hälsoeffekter* (Socio-economic valuation of nitrogen-oxide-related health effects), NIER, 1996.

Hamilton, Kirk, "Pollution and Pollution Abatement in the National Accounts," *Review of Income and Wealth*, 42(1), March 1996.

Hartwick, John M., "Natural Resources, National Accounting and Economic Depreciation," *Journal of Public Economics*, 43, 291–304, 1990.

Heal, Geoffrey and Bengt Kriström, *National Income and the Environment*, Working paper, Columbia University, 1999.

Hicks, John R., *Value and Capital*, 2nd edition, Oxford University Press, New York, 1939.

Leksell, Ingemar and Lars Löfgren, *Värdering av lokala luftföroreningseffekter—hur värdera bilavgasernas hälsoeffekter i tätorter?* (Valuation of local air pollution effects—how to value the health effects of car exhausts transports in densely populated areas), Institutionen för tillämpad miljövetenskap, Göteborgs universitet, KFB-rapport 1995:5, Kommunikationsberedningen, Stockholm, 1995.

McLaughlin, S. B., "Effects of air pollution on forests, a critical review," *Journal of Air Pollution Control Association*, 35, 1985.

Mäler, Karl-Göran, "National Accounts and Environmental Resources," *Environmental and Resource Economics*, 1, 1–15, 1991.

Munasinghe, Mohan and Wilfrido Cruz, *Economywide Policies and the Environment: Lessons from Experience*, Environment paper no.10, World Bank, 1995.

NIER, *Svenska miljöräkenskaper för svavel och kväve* och *Sveriges kostnader för kväveutsläpp* (*Swedish environmental accounts for sulfur and nitrogen* and *The costs for nitrogen emission in Sweden*), Miljöräkenskapsserien, 9, 1998.

Pleijel, H., L. Hedvåg, and K. P. Haasund, *Ekonomiska konsekvenser av det marknära ozonets påverkan på jordbruksgrödor* (Estimates of the total physical and economic yield losses to Swedish agriculture caused by ozone in the lower layers of the atmosphere), report no. 3862, 1990.

Repetto, R., W. McGrath, M. Wells, C. Beer, and F. Rossini, *Wasting Assets: Natural Resources in the National Income Accounts*, World Resources Institute, Washington D.C., 1989.

Skånberg, Kristian, *En beräkning av skogsförsurningens skadekostnader* (A calculation of the costs of damage due to forest acidification), in report 1998:10, NIER, 1998.

Solow, Robert M., "On the Intergenerational Allocation of Natural Resources," *Scandinavian Journal of Economics*, 88(1), 141–9, 1986.

Sverdrup, Harald and Per Warfvinge, *Critical Load of Acidity for Swedish Forests*, Lunds Tekniska Högskola, 1994.

UN, *Integrated Environmental and Economic Accounting, Interim Version*, ST/ESA/STAT, series F, no. 61, 1993.

Usher, D., *The Measurement of Economic Growth*, Blackwell, Oxford, 1981.

Weitzman, Martin L., "On the welfare significance of national product in a dynamic economy," *Quarterly Journal of Economics*, 90, 156–62, 1976.

———, "The linearized Hamiltonian as Comprehensive NDP," *Environment and Development Economics*, 5(1–2), 55–68, 2000.