WORKING PAPER No.73
May, 2000

CORRECTING NDP FOR SO2 AND NOX EMISSIONS: IMPLEMENTATION OF A THEORETICAL MODEL IN PRACTICE

SOFIA AHLROTH

Correcting NDP for SO_2 and NO_x emissions: Implementation of a theoretical model in practice[*]

Sofia Ahlroth
National Institute of Economic Research, Stockholm

Abstract

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 twice as large as the Swedish sulfur tax if all costs are taken into account.

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[*] I am deeply indebted to dr. Anni Huhtala and Kristian Skånberg, National Institute of Economic Research, Stockholm, and to prof. Bengt Kriström, Swedish University of Agricultural Sciences, Umeå, without whose support this paper would not have been written. Their engagement and helpful comments are most appreciated. Many thanks also to dr. Peter Parks, Rutgers University, USA, and dr. Santiago Rubio, University of Valencia, Spain, for detailed and constructive comments. All remaining mistakes are entirely my own.

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. 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 e.g. 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 e.g. 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 on 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 80s and beginning of the 90s, 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] and Munasinghe&Cruz [1995]). A number of statistical offices in industrialized countries also began compiling environmental national accounts as early as in the 70s and the 80s. 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 on year. The paper thus does not deal with accumulated damage, i.e. the state of the environment.

2 A theoretical model

In this section I will outline a model for the environmental adjustments made in the empirical study carried out at the Swedish National Institute of Economic Research (NIER). The aim is to provide a structure for the damage valuations.

In the study, 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) are 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 current flow of pollutants; the other effects are due to the size of the stock of pollutants in the ecosystems.

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 which method was used to estimate the prices.

Table 1. Components in the valuation study and corresponding variables in the model

Environmental protection expenditures	Liming, sewage water treatment	λ_K f(b)	Cost estimation
	Health care costs, catalytic converters	λ_C times part of C	Cost estimation
	Corrosion	λ_K , λ_C times part of F and C	Dose-response function
Changes in market value	Nitrate in groundwater	λ_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)	λ_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

All the components relate to emissions and effects of different forms of nitrogen (both to air and water) and sulfur dioxide.[1] 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 estates 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, where the willingness to pay for avoiding damages from acidification, eutrofication, nitrate in groundwater and air pollution (nitrogen oxides) was asked for.

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.

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.

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 $U_{Ei} < 0$.

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[1] For a description of the valuations, see NIER[1998].

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, **E**, so as to maximize[2]

$$(4.1)\quad \int_t^{\infty} U(C,\bar{E},\bar{X})e^{-rt}\,dt$$

s.t.

$$(4.2)\quad \dot{K} = F(K,L,R,E) - C - \sum_j f_j(b_j) - dK - \sum_j k_j(E_j), \qquad j = SO_2, NO_x, NH_3$$

$$(4.3)\quad \dot{L} = n - l(E_{NOx}), \qquad\qquad n - l(E) > 0$$

$$(4.4)\quad \dot{S}_i = \sum_j g_i(S_i, X_j) - R,\ i = \ forest, fish \quad j = SO_2, NO_x, NH_3$$

$$(4.5)\quad \dot{X}_j = (1-a_j)E_j - b_j + I_j - d_j, \quad j = SO_2, NO_x, NH_3, \ \ 0 \le a \le 1$$

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
δ = 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)
α = part of emissions that is exported
τ = 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.

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

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 d, and additional depreciation $k(\boldsymbol{E})$ which depends on current emissions (here, additional corrosion due to acidification). The change in the stock of real capital (eq. 4.2) 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. E.g. 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. Population growth is not a central issue in this context and thus is represented only by a constant, to keep the functions simple. The health effects on labor supply $l(E)$ in this study are very small compared to population growth, and hence the assumption n>l(E) is not a very daring one. Nevertheless, population growth may be represented by a more plausible function in future versions of the model.

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,**X**)). The growth function *g* is non-decreasing in S and non-increasing in **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 linearized current value Hamiltonian of the optimal growth problem is[3]

$$
\begin{aligned}
H(t) = {} & U_c C + U_X X + U_E E + l_K\left[F(K,L,R,E) - C - f(b) - dK - k(E)\right] + l_L\left[n - l(E)\right] \\
& + l_S\left[g(S,X) - R\right] + l_X\left[(1-a)E - b + I - d\right]
\end{aligned}
$$

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

The first order conditions are

$$(4.6)\quad \frac{\partial H}{\partial C} = 0 \Rightarrow U_C = \lambda_K$$

$$(4.7)\quad \frac{\partial H}{\partial R} = 0 \Rightarrow \lambda_S = \lambda_K F_R$$

$$(4.8)\quad \frac{\partial H}{\partial E} = 0 \Rightarrow U_E + (1-a)\, \lambda_X - \lambda_K (F_E - k_E) - \lambda_L l_E = 0$$

$$(4.9)\quad \frac{\partial H}{\partial b} = 0 \Rightarrow -\lambda_K f_b - \lambda_X = 0$$

The shadow prices of stocks are given by the differential equations

$$(4.9)\quad \dot{\lambda}_K = r\, \lambda_K - \frac{\partial H}{\partial K} = \lambda_K (r - F_K + \delta)$$

$$(4.10)\quad \dot{\lambda}_L = r\, \lambda_L - \frac{\partial H}{\partial L} = r\, \lambda_L - \lambda_K F_L$$

$$(4.11)\quad \dot{\lambda}_S = r\, \lambda_S - \frac{\partial H}{\partial S} = \lambda_S (r - g_S)$$

$$(4.12)\quad \dot{\lambda}_X = r\, \lambda_X - \frac{\partial H}{\partial X} = r\, \lambda_X - U_X - \lambda_S g_X$$

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 δ.

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, λ_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

$$l_X = \int_t^{\infty} (U_X + l_S g_X)\, e^{-r(t-t)} dt$$

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.[4] 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:

$$EDP = U_C C + l_K \dot{K} + l_L \dot{L} + l_S \dot{S} + U_E E + U_X X + l_X \dot{X}$$

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 the pollutants have multiple effects. In the case of sulfur and nitrogen, they effect health, crops etcetera 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. Term 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.

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[4] 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.

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 on 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.[5] 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. An alternative calculation would be to internalize the external effects in the prices by introducing optimal taxes.[6]

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[5] In the model I have separated the accelerated depreciation due to pollution from the “normal” depreciation.

[6] See Aronsson and Löfgren [1996].

3 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 sectors' share in the total load, taking into consideration the higher impact of Swedish emissions in 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 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.

Table 2. Environmental accounts for emissions of sulfur and nitrogen for 1991

			Percentage of NDP *	
	Total deposition in Sweden	*Attributed to Swedish emissions*	*Total*	*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.

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

Recall from section 4 the Hamiltonian for the model:

$$H(t) = U_c C + U_X X + U_E E + l_K\left[F(K,L,R,E) - C - f(b) - dK - k(E)\right] + l_L\left[n - l(E)\right]$$
$$+ l_S\left[g(S,X) - R\right] + l_X\left[(1-a)E - b + I - d\right]$$

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

$$EDP = C + \dot{K} + r_L \dot{L} + r_S \dot{S} + r_X \dot{X} + P_E E + P_X X\,,$$
$$r_i = \frac{l_i}{U_C},\ \ i = L, S, X$$
$$P_i = \frac{U_i}{U_C},\ \ i = E, X$$

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

$$l_X = \int_t^{\infty} (U_X + l_S g_X)\ e^{-r(t-t)} dt$$

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 houesholds' 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

$$EDP = C + \dot{K} + r_L \dot{L} + r_S \dot{S} + r_S g_X \dot{X} + P_E E + P_X (X + \dot{X})$$

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, λ_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 λ_L that is approximated with average wages. From the model, we see that in steady state λ_L can be written as

$$l_L = \frac{l_K F_L}{r}$$

where λ_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. ρ_L is thus simply approximated with the wage. The same line of argument holds for the shadow price of natural capital λ_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 $ 2331 million.

Table 3. Components of adjustment of NDP

	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	ρ_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
“ Lakes	P_x(X+dX/dt)	882	CV study
“ Forest	P_x(X+dX/dt)	271	CV study
Nitrate in groundwater	P_x(X+dX/dt)	235	CV study
Health	P_EE	388	CV study
Total adjustment		**2331**	

A ‘sulfur-nitrogen adjusted’ NDP – here called EDP – can thus be calculated:

$$EDP = 146588 - 49 + 647 - 105 - 1788 - 388 = 144905 \ \ million \ USD$$

$$(NDP + r_L \dot{L} + r_S \dot{S} + r_S g_X \dot{X} + P_X (X + \dot{X}) + P_E E)$$

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] and [1998]), not of the *change* in welfare as in Heal and Kriström[1999] or Mäler [1991]. 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 $ 2331 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 consumer’s surplus, the adjustment is reduced to US $ 154 million. To give some perspective of the order of magnitude, it can be mentioned that the amount paid for social allowances in Sweden 1991 were US $ 659 million and the agricultural subsidies were 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 that could have been used for other purposes, had it not been for pollution.

The costs for the relevant part of corrosion amount to US $ 227 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-leaves cause a production loss of US $ 27 million. Damages to crops amount to US $ 59 million. These two effects represent consumption foregone, and could be added to conventional NDP to show ‘potential NDP’.[7]

It may be interesting to compare the estimated costs of pollution with current taxes on sulfur and nitrogen. The damage costs are estimated for 1991, the same year as

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[7] The total value of the crop damages due to tropospherical ozone is US $ 118 million per year (see Pleijel and Haasund [1990]).

the sulfur tax was introduced and one year before the charge on nitrogen oxides. The tax on nitrogen in fertilizers was introduced in1984.

Sulfur accounts for two thirds of the acidification of soil and water and for 90 percent of additional corrosion. The average cost for the negative effects of sulfur deposition in Sweden is in this study estimated to US $ 5.50 per kilo sulfur. Including also the costs that have lowered the conventional NDP (capital depreciation), the average cost is US $ 7.30 per kilo sulfur. The sulfur tax in Sweden is US $ 3.50 per kilo sulfur.[8]

The total cost due to nitrogen amounts to US $ 1838 million. The average cost of all nitrogen emissions is US $ 6.60 per kilo nitrogen, including current costs for crop loss and corrosion damages. Excluding the latter costs, the average cost is US $ 6.20 per kilo nitrogen. Attributing the cost of nitrogen to different forms of nitrogen is complicated. Corrosion and health effects of air pollution in cities are caused by nitrogen oxides. The other impacts: eutrofication, acidification and nitrate in groundwater are influenced by both nitrogen emissions to air (NO_x, NH_3) and to soil and water (N). A very rough attempt to attribute the costs to different nitrogen emissions results, using the PEE weights[9], in US $ 6.30 per kilo nitrogen for NO_x and US $ 3.90 per kilo nitrogen for NH_3. The damage cost for nitrogen emissions to soil and water is estimated to US $ 6.85 per kilo nitrogen.

There is no general tax on nitrogen oxides in Sweden, since NO_x emissions are not primarily fuel-related like sulfur and carbon dioxide.[10] Taxes on nitrogen oxides must

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[8] The tax was introduced in 1991, and is estimated to have reduced the sulfur emissions by 9 500 tons, or 19 000 tons sulfur dioxide. The environmental target for sulfur emissions, 100 000 kton by the year 2000, has been met. The sulfur deposition in Sweden is still above the critical load limits, mostly because of imported emissions. The Swedish sulfur emissions could be further reduced by relaxing some of the exceptions and by lowering the limit of allowed sulfur content in fuels (which is now 0.1 %).

[9] Netherlands CBS [1993].

[10] The nitrogen deposition is above the critical load in Sweden. As with sulfur, most of it is imported. Sweden had set a target for nitrogen oxides for the year 1995, reducing emissions by 30 percent from the 1980 emission level, which is a reduction by 136 000 ton, but by 1995 the emissions were only reduced by 20 %, i.e. 90 000 ton, of which 10 000 can be attributed to the NOx charge, as noted above. This equals 40 percent of the emissions of the taxed energy production plants, which is above the target, if all sectors were supposed to reduce their emissions by the same amount.

therefore be based on direct measurement of the emissions. There is a charge on NO_x emissions for certain energy production plants, which is refunded to the plants according to their share in the total produced energy. The charge is US $ 4.71 per kilo NO_x, which is approximately US $ 15.29 per kilo N. The charge was introduced in 1992, and is estimated to have reduced NO_x emissions by 10 000 ton.[11] There are also taxes on fertilizers. The environmental tax on nitrogen in fertilizers was US $ 0.07 per kilogram in 1991. At that time there was also a price regulation charge of US $ 0.21 per kilogram nitrogen, so the total “nitrogen tax” on fertilizers was US $ 0.28 per kilo N.[12]

A comparison between these taxes and the estimated costs are not as straightforward as in the case of sulfur. The taxes cover only a small part of the sources. The energy sector emits around 10 percent of the Swedish NO_x emissions. The by far largest source of nitrogen oxide emissions is transports, which are not taxed explicitly for nitrogen emissions (although gasoline is heavily taxed). The charge on the energy production plants may seem high compared with the calculated damage costs, but since it is refunded the actually paid ‘tax’ varies from plant to plant. The tax on nitrogen in fertilizers is low compared to the estimated damage cost. The fertilizer-using sector, agriculture, causes around 50 percent of the nitrogen emissions to soil and water. The next largest source is the sewage sector.[13]

4 Concluding comments

In accounting, it is important to avoid double-counting and other inconsistencies. A theoretical model 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

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[11] EPA[1997].

[12] Ibid.

[13] Statistics Sweden [1996b]

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 are 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 a 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 welfare effects concern, for reasons mentioned above, reduction of the current pollution stock, and thus in general is 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 if 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 has 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, 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 e.g. one specific emission.

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