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Abstract

Human capital is an important component of economic growth. The article extends a theoretical model for comprehensive national accounting to the welfare effects of pollution on human capital. The model includes a production externality in the form of a flow of air pollutants that cause both direct disutility and indirect welfare effects by negatively affecting the productivity of labor. We show that defensive medical expenditures or healthcare costs allocated to mitigating the disutility of air pollution should not be deducted from conventional net national product (NNP), whereas the value of the perceived disutility of illness episodes caused by pollution should be subtracted from NNP. We derive a marginal cost-benefit rule for an optimal level of pollution given its negative health effects. The rule can be used for determining an optimal tax on harmful emissions. Finally, we outline a scheme for empirical comprehensive accounting and for estimation of an emissions tax.

Keywords: externalities, defensive expenditures, respiratory illnesses, air pollution, green accounting

JEL Codes: I10, O4, Q25

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1. Introduction

It is generally acknowledged that human capital is an important factor contributing to economic growth. The composition and measurement of human capital have been studied empirically in macroeconomics with the interesting finding that not only education but also good health has a significant positive effect on aggregate output (see, e.g. Bloom et al. 2001, Nordhaus 2002). In previous studies, the focus on health has mainly been motivated by an interest in life expectancy, with a natural emphasis on its potential productivity effects in developing countries (Strauss and Thomas 1998). However, epidemiological studies have accumulated evidence of other types of health effects, which are typical of so-called industrialized countries as well. We are interested in the health impact assessment of exposure to air pollution (see, e.g., EPA 1999). Previous economic studies valuing these effects in monetary terms indicate that health impacts make up a significant portion of the damage costs of air pollution (e.g., EC-DG XII 1995, Holland et al. 1999, Markandya and Pavan 1999). In particular, the impacts of reductions in air pollution on asthma symptoms are becoming increasingly important (Kunzli et al. 2000).

The purpose of this paper is to present a theoretical framework for taking into account the health effects of air pollutants in comprehensive, environmentally adjusted national accounting. The framework clarifies what we actually want to measure in green accounting, and we discuss potential policy-relevant uses of such an accounting framework. The framework reveals the importance of determining a consistent objective function for each specific environmental problem and suggests how monetary valuation of the health effects of air pollution might be carried out in practice.

We adopt an optimal-control modeling framework for the measurement of national income. The objective function of the economy or, specifically, the maximized Hamiltonian, is interpreted as a measure of Hicksian income.[1] It may appear counterintuitive to use an optimization modeling approach to measure and value environmental impacts which typically are externalities and which actually cause the economy deviate from a socially optimal path (see, e.g., Aaheim and Nyborg 1996). The Hamiltonian framework proves justified, however, when identification of negative environmental externalities is necessary to understand the discrepancy between social and private optima. Since a social optimum is, by definition, a normative concept, empirical valuation of environmental externalities based on the Hamiltonian optimal control framework can provide information on *how far* the perceived private optimum currently is from the perceived social optimum. Therefore, planning socially optimal policy instruments (such as taxes or subsidies) is conditional upon these "perceived" states of worlds; in other words, all policy choices are ultimately contingent upon inherent valuation, distribution of income and the like. The subjective optimality becomes even more obvious in our analysis where health effects are concerned, since personal health is at least partially a result of an individual's endogenous choices. Consequently, when identifying the most relevant components of environmentally adjusted national accounts for health impacts, the applicability of the Hamiltonian framework is pronounced, because without such a consistent framework the adjustments and their interpretation become more or less arbitrary.

In empirical analyses by Ahlroth (2000) and Skånberg (2001), the theoretical Hamiltonian framework has been tested in practice and has been shown to be applicable in the construction of environmental accounts. Our analytical framework extends the modeling to a production externality in the form of a flow of air pollutants that cause both direct disutility and indirect welfare effects by negatively affecting the productivity of labor. Such a framework is needed, since, as Williams III (2002) has observed, many recent studies examining the costs of pollution regulation make restrictive assumptions regarding preferences and ignore key links between pollution, human health and labor productivity. Having a proper modeling framework minimizes the risk of "double counting" of pollution-related health impacts that affect the economy in various ways. In addition, the framework addresses the discussion on several important policy issues: the interpretation of mitigation costs, or defensive expenditures in conventional national accounts; the regulation of air pollution impairing health; the basis for determining an optimal tax on harmful emissions; and the extent to which the total social costs of health impacts of air pollution can be approximated at the aggregate national level in environmentally extended accounts.

The paper is organized as follows. First, we present an optimal control modeling framework to investigate account adjustments with a special emphasis on the health impacts of air pollution. We then go on to discuss the suggestion that defensive expenditures be deducted from the national accounts and show ideal account deductions reflecting welfare changes. A marginal cost-benefit rule for optimal environmental policy is derived, and a scheme is presented for empirical estimation of the different components derived in the theoretical accounting model. Finally, the total social costs of health impacts of air pollution are discussed, and suggestions for further analysis are made.

2. The model

We present a simple dynamic model to illustrate how an accounting system that takes into account health effects of air pollution could be developed. The accounting framework is modeled as a social planner's optimization problem where a fixed amount of labor is allocated between production of a composite commodity and the healthcare sector. Inputs used in the healthcare sector should be interpreted as defensive expenditures undertaken to improve health. Social welfare is maximized when consumers maximize their utility. Utility is derived from consumption of a composite commodity, C. Air pollution causes disutility, and the disutility of pollutants, P, in the form of "pain and suffering" can be alleviated with inputs for healthcare and mitigation, L_2. In other words, defensive expenditures offset the impact of negative externalities. Formally, utility is expressed as $U(C)$ and disutility as $D(P, L_2)$ such that $D_P > 0$ and $D_{L_2} < 0$. It should be emphasized that we model health impacts as disutility from illness and not as utility from health. In the literature, health has been modeled as positive output (see, e.g., Navrud, 2001; Tolley et al., 1994) or as a capital stock in the utility function (Aronsson et al., 1994) when studying analytically the measurement of welfare and health effects induced by, for example, pollution. We acknowledge the positive utility from health, but our approach is constrained on the empirical level by the well-known difficulty of measuring and valuing human health. Since it is difficult to measure a positive value for “normal” health status in accounting terms, we opt for existing valuation methods suitable for estimating damage to health, or negative impacts (See also SEEA (2002), Chapter 10, 10.150).

In principle, we are interested in a health risk capturing the proportion of the total number of people affected by exposure to a risk factor such as pollutants or smoking. Since it is difficult to identify all possible risk factors in practice, we use in our theoretical model a weight that captures the proportion of the output of the healthcare sector generated in treating illnesses related to air pollution. The weight is denoted by $a(Q)$, acknowledging that a is a function of personal characteristics, Q. The additional demand for services of healthcare sector $h(\cdot)$ due to air pollution is modeled by $g(\cdot)$, and $g(P)a(Q)h(L_2)$ constitutes then “unnecessary” consumption of healthcare services due to pollution, which crowds out capital investments.[2]

Aggregated net utility, discounted by a constant interest rate, r, is maximized

$$\max \int_0^\infty [U(C) - D(P, L_2)]e^{-rt}dt$$

subject to

(1) $\dot{K} = f(K, L_1, P) - C - g(P)a(Q)h(L_2) - dK$

(2) $K(0) = K_0$

(3) $b(P)\overline{L} = L_1 + L_2$

where K = stock of capital

K_0 = initial level of capital (given)

d = depreciation rate of capital stock

$\overline{L}$ = total labor available in the economy

L_1 = labor input used in producing the consumption commodity, C

L_2 = labor input used in healthcare sector

f = production function for the composite commodity,

$f_K > 0,\ f_{L_1} > 0,\ f_P > 0$

h = production function for healthcare services, $h_{L_2} > 0$

$b(x)$ = the effect of air pollutants on the productivity of labor, $b_P<0$

and $b(P)=1$, when $P=0$

$b(P)<1$, when $P>0$

$\gamma(x)$ = the effect of air pollutants on the demand for healthcare services, $g_P>0$

and $g(P)=1$, when $P=0$

$g(P)>1$, when $P>0$

It should be noted that there is no *additional* demand for healthcare, or $g(0)=1$, if there is no air pollution; $g(P)>1$ otherwise. Adjustment for the productivity of labor due to air pollution is modeled in a similar manner with the function $b(x)$. Without pollution, there is no productivity adjustment, or $b(P)=1$, but if pollution exists, its impact on the productivity of labor is negative, or $b(P)<1$ when $P>0$.

The Lagrangian for this optimal control problem, i.e., the current value Hamiltonian plus the constraint on the total amount of labor inputs, is

(4) $$L = U(C) - D(P, L_2) + l\,[\,f(K, L_1, P) - C - g(P)a(Q)h(L_2) - dK] + w(b(P)\bar{L} - L_1 - L_2),$$

with l and w denoting the shadow price of capital and the Lagrangian multiplier for the labor input constraint, respectively (in utility terms). The additional necessary conditions are

(5) $$\partial L / \partial C = U_C - l = 0$$

(6) $$\partial L / \partial P = -D_P + l f_P - l\,a(Q)h(L_2)g_P + w\bar{L}\,b_P = 0$$

(7) $$\partial L / \partial L_1 = l f_{L_1} - w = 0$$

(8) $$\partial L / \partial L_2 = -D_{L_2} - l\,g(P)a(Q)h_{L_2} - w = 0$$

(9) $$\dot{l} = (r + d - f_K)\,l$$

Equations (5), (7) and (8) define the optimality of consumption of the composite commodity and healthcare services. In optimum, the marginal utility of consumption, U_C, equals the marginal cost of producing the composite commodity, w / f_{L_1}, which must equal the net marginal benefit from healthcare $[-D_{L_2} - w] / g(P)a(Q)h_{L_2}$. Equation (9) is the time derivative of the shadow price of the capital stock; it incorporates the golden rule for optimal steady state investment, $f_K = r + d$, i.e., the marginal product of capital equals depreciation and interest rate. Finally, equation (6) gives an efficiency condition for pollution. We return to this condition when discussing an appropriate cost-benefit rule for an optimal level of pollution.

The current value Hamiltonian is interpretable as Net National Product (NNP) in utility terms. Rewriting the Hamiltonian with a linearized utility function yields

$$\overline{H} = U_C C - D_P P - D_{L_2} L_2 + l\dot{K} .$$

Dividing $\overline{H}$ by the marginal utility of consumption, U_C, we obtain a linearized measure for *partially environmentally adjusted Net National Product:*

$$\text{(10)} \quad \overline{NNP} = C - \frac{D_P}{U_C} P - \frac{D_{L_2}}{U_C} L_2 + \dot{K} .$$

The first and last term on the right-hand side (RHS) of equation (10) are consumption and investments as measured in the conventional accounts. The second term on the RHS is an additional factor that adjusts the national accounts to reflect welfare effects of pollution. The negative term $-[D_P / U_C]P$ captures the direct, perceived disutility of symptoms related to air pollutants. The third term, $-[D_{L_2} / U_C]L_2$, is positive (since D_{L_2} is negative) and measures the avoidance of the disutility arising in the healthcare sector from mitigating problems and symptoms associated with pollution-related (e.g. respiratory) illnesses. Since the output of the healthcare sector is measured by production costs, the term is already part of conventional accounts and should *not* be subtracted from the NNP to reflect the welfare effects of air pollution. The logic is that while it may be negative from a social point of view that the output of the healthcare sector increases due to pollution, the increase nevertheless contributes to the NNP. The detrimental effects of pollution are implicitly captured by the level of the NNP, since the resources devoted to healthcare crowd out other consumption and more beneficial investments.

An obvious implication of the above framework is that pollution impairing health and reducing the labor supply does not justify a separate (extra) adjustment for the sake of a comprehensive NNP. The reason is evident: this part of the overall pollution effects is already incorporated in the conventional NNP in that output from sectors using labor inputs is already lower due to sick leaves and the like.

However, effects in the form of decreased health due to pollution are properly taken into account only in an optimizing economy. A welfare-maximizing society will pollute up to the point where the benefit from an additional pollution unit just equals the social cost of that unit. This is seen from equation (6), which provides a guideline for a cost-benefit rule for an optimal level of pollution:

$$(6') \quad f_P = (D_P / U_C) - w\overline{L}(b_P / U_C) + a(Q)h(L_2)g_P .$$

(I) (II) (III)

According to equation (6'), the marginal physical product of pollution, f_P, must equal the marginal disutility of pollution (I), the impaired marginal productivity of labor (II), and the marginal increase in the output of the healthcare sector, including all medical expenses, such as medicine (III), which crowds out other consumption or investments. In optimum, factor input is paid the value of its marginal product. Since we do not know the actual value of marginal product of pollution, the value of the RHS of equation (6') tells how valuable the marginal product of pollution should be in order to justify the externality costs to society. Consequently, to impose an optimal emissions tax on a unit of pollution in practice, the terms I, II and III of the RHS of (6') should be assigned monetary values.

What should be recognized from equation (6’) is that an optimal tax has, in principle, an individual specific component – the individual characteristics captured in $a(Q)$ – because people can affect their health status and resistance to air pollution through their behavior. For example, smoking makes people more prone to asthma. On the other hand, some people voluntarily take costly averting measures (e.g., staying indoors when air quality is low) to minimize the risk of distressful asthma attacks. Hence, it would be optimal to tax externalities at different rates depending on whether individuals exaggerate/mitigate the marginal social damage involved. Discussion of a differentiated tax originates from the early theoretical works of Diamond (1973) and Sandmo (1976), but implementing such an optimal tax has been difficult in practice. For simplicity’s sake and to be able to exploit existing data in our empirical illustration, we average across individuals exhibiting different tendencies and assume $a(Q)$ to reflect a certain fraction of the healthcare services devoted to treating illnesses related to air pollution.

3. Empirical estimation of the social health costs of air pollution and calculation of a partially adjusted NNP

In this section, we show how the social costs of health effects caused by air pollution can be estimated. We outline a scheme for the empirical calculation of an optimal tax on air pollution causing health effects. Thereafter, we discuss derivation of the total social health costs attributable to pollution. Finally, we show which components of these total costs are appropriate for inclusion in environmental satellite accounts.

In assessing the productivity loss caused by pollution, use can be made of what is known as the dose-response functions. This is a technique whereby the existence of a pollutant is correlated with the “receptors” of different types of illness. A seminal study investigating the pollution-morbidity link is that of Ostro (1983). In practice, the extent of health damage is measured by restricted activity days or work loss days due to pollutants. Once this health effect is established, it should be valued in monetary terms. Lost output in terms of labor income lost due to restricted activity serves as a first, most conservative, monetary estimate for the productivity loss caused by pollution to health.

Next, a comprehensive estimate of pollution damage to health must include the cost of "pain and suffering", or perceived disutility from health symptoms. Since this is a very individual- specific cost, an appropriate estimate can be obtained by undertaking a survey of stated willingness to pay. Finally, the medical care costs attributable to pollution must be identified to complete the estimation of the total social health cost of pollution.

Given the overall valuation methods discussed above, we can now identify the marginal social health costs of air pollution by applying the optimization rule derived in equation (6'). The trade-off between the use of polluting input, P, and labor, L_1, becomes evident if we rewrite the second term of the RHS of equation (6') using (5) and (7) as follows:

$$f_P = (D_P / U_C) - \bar{L} b_P f_{L_1} + a(Q) h(L_2) g_P .$$

Hence, the value of an additional unit of pollutant can be approximated by measuring the cost of pollution caused to society in the form of deterioration in people's health.

To carry out the measurement in practice, we need data to calculate

- the direct disutility of symptoms associated with air pollution; this is typically estimated as willingness to pay for avoiding illness episodes with respiratory symptoms related to air pollution; a contingent valuation or benefit transfer study could be applicable, (D_P / U_C)

- impacts of pollution on the productivity of labor input; requires an estimate using a dose-response relationship, (b_P), the total amount of labor available in the economy, ($\overline{L}$), and the productivity of labor, or wage rate, ($f_{L_1} = w / U_C$)
- pollution-related medical care costs, including hospital and prescription drug expenditures, $a(Q)h(L_2)g_P$.

For illustrative purposes, we show the results of a calculation exercise carried out using data applicable for Sweden. Table 1 summarizes the data and figures used in approximating the costs identified above and gives a rough estimate of the social health costs of nitrogen dioxide emissions in Sweden. However, the tentative nature of the cost estimate should be borne in mind: Table 1 does not provide highly reliable monetary estimates as such but, rather, illustrates the applicability of the measurement framework.

The figures in Table 1 have been collected from several studies (see also Appendix). First, we use an up-to-date analysis of the dose-concentration relationship between air quality and health in Sweden. The results of Samakovlis et al. (2002) indicate that a unit ($\mu g/m^3$) increase in the monthly average of nitrogen dioxide (NO_2) leads on average to an increase of 3 percent in respiratory-related restricted activity days (RRADs) in Sweden. In the sample of a national health survey, the mean RRAD, among the persons that reported RRADs, was 5 for the two-week period investigated. Annually, this translates into 130 days. Assuming that the proportion of people with RRADs in the sample is representative of the Swedish population, we can calculate the total yearly number of RRADs in Sweden as (130*0.035*6488846), with one unit increase in the monthly average of NO_2 leading to a total of 885 727 additional RRADs.

Second, morbidity effects from air pollution have been valued for the Netherlands, Norway, Portugal, Spain and the UK in a recent European study (Ready et al. 2001). The value of avoidance of episodes of respiratory ill health was estimated through national contingent valuation (CV) surveys. The surveys aimed at determining how much individuals in the respective countries were willing to pay to avoid the pain and discomfort that result from suffering such an episode. For Norway, the mean willingness to pay (WTP) to avoid a minor episode (lasting one day) was SEK 540. Major respiratory restricted activity episodes were valued at SEK 1797 for an episode lasting 3 days, and at SEK 4537 for an episode lasting 8 days. In Table 1, the Norwegian mean WTP figures are used as rough estimates for approximating the corresponding WTP in Sweden.

Third, according to ORNL/RFF(Oak Ridge National Laboratory/Resources for the Future, 1994) 38 percent of the restricted activity days are in general minor restricted activity days. Using the number of additional RRADs due to pollution derived in the Swedish dose-concentration study (885 727), and the figures from the Norwegian CV study, the increase in disutility from one unit increase in NO_2 becomes (885 727*0.38*540)=SEK 182 million for minor RRADs and (885 727*0.62*576)=SEK 316 million for major RRADs. The sum SEK 498 million represents the marginal disutility of pollution (term I) in equation 6’.

Finally, according to Alfsen and Rosendahl (1996), the labor productivity loss for minor RRAD is around 10% of wages. Given an average monthly salary of SEK 19400, the average daily salary is 19400/30=647. Approximately 82.7 percent of the included Swedish population are of working age. Assuming that the share of minor and major RRADs in the employed population is proportional to the total population, the productivity loss for one unit increase in NO_2 (term II in equation 6’) then becomes (0.827*336576*647*0.10)= SEK 18 million for minor RRADs and (0.827*549151*647)=SEK 294 million for major RRADs.

Table 1 Estimate of disutility and productivity loss associated with an increase of one microgram in the concentration of NO_2 emissions

Estimate of additional respiratory-related restricted activity days (RRADs) per year	
Mean RRAD in sample per year (5*26)	130
Share of people with RRADs in sample	3.5%
Swedish population between ages 19-81	6 488 846
(A) Total RRADs in Sweden per year (130*0.035*6488846)	**29 524 249**
(B) Dose-Response coefficient	**0.03**
(A)& (B) ➔ (C) Total number of additional RRADs per year (= 29 524 249*0.03)	**885 727**
of which (1) minor RRADs (38%)	336 576
(2) major RRADs (62%)	549 151
(D) Disutility value of additional RRADs per year	
(1) WTP to avoid one minor RRAD	SEK 540
(2) WTP to avoid one major RRAD ((4537+1797)/11)	SEK 576
TOTAL (336576*540 +549151*576)	**SEK 498 062 016**
(E) Productivity loss of additional RRADs per year	
Average Swedish daily wage	SEK 647
➔ (1) Loss per minor RRAD (10% of daily wage)	SEK 64.7
(2) Loss per major RRAD (100% of daily wage)	SEK 647
Share of population of working age	82.7%
TOTAL (0.827*336576*64.7) + (0.827*549151*647)	**SEK 311 842 815**
MARGINAL COST OF RESTRICTED ACTIVITY DAYS	**SEK 809 904 831**

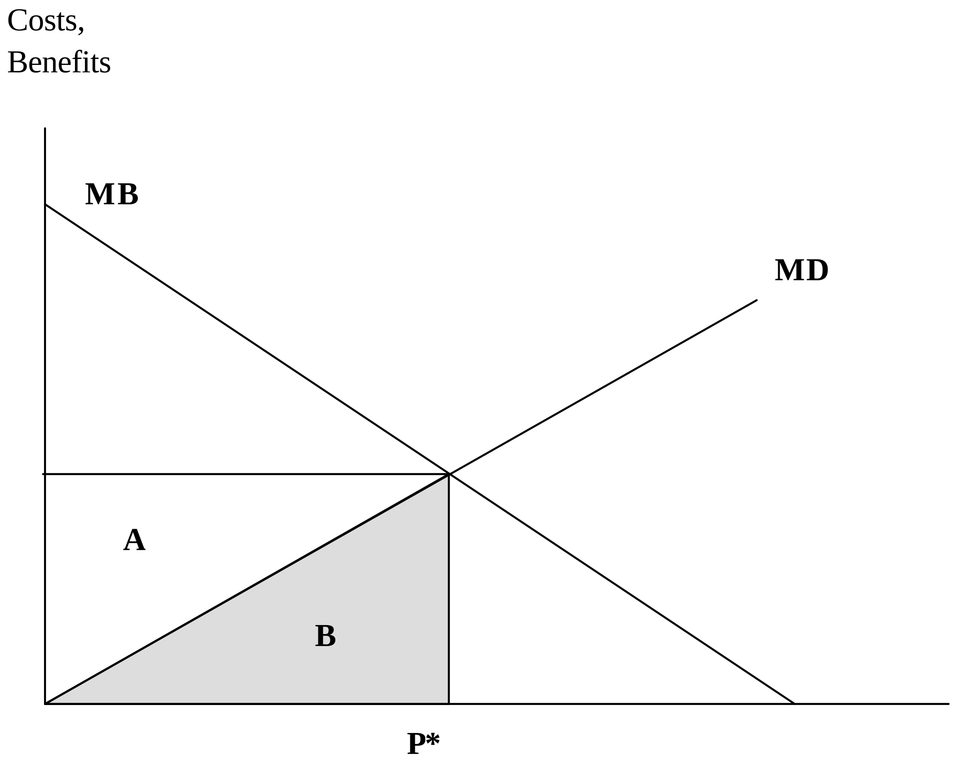
Sources: (A) NMHE 1999; (B) Samakovlis et al. (2003); (C) shares of minor vs. major restricted activity days: ORNL/RFF (1994); (D) Ready et al. (2001); (E) Statistics Sweden and Alfsen and Rosendahl (1996). See also Appendix.

To calculate the optimal tax, medical expenses related to a one unit increase in NO_2 (term III in equation 6') should also be taken into account. Preferably, we should have an estimate of medical expenses for all respiratory illnesses and the proportion of the Swedish population with respiratory illnesses. Since people can be diagnosed with more than one type of respiratory illnesses, we focus on asthma. About 8 % of the Swedish population has asthma. In a recent study, it has been estimated that the total cost for asthma medical services in 1999 amounted to SEK 1.452 billion (Bohlin et al. 2002). These costs consist of medicine (SEK 652 million), consultations with a medical doctor for respiratory ailments (SEK 715 million), and hospital admissions (SEK 85 million). Even though there is scientific evidence of increased respiratory-related hospital admissions on high air pollution days (e.g., Bellander et al. 1999, Thurston et al. 1997), it is difficult, if not impossible, to estimate how much of these costs should be attributed to air pollution in general and to an increase in the NO_2 concentration in particular. Therefore we have decided to exclude these costs and consider our approximation of social marginal health damage, in terms of disutility and productivity loss, as a conservative estimate.

As is shown in Table 1, the disutility and productivity loss associated with one microgram/cubic meter ($\mu g/m^3$) increase of NO_2 is estimated to be about SEK 810 million, or € 89 million. To derive an estimate of the marginal health damage of one kilogram of NO_2, we should translate concentrations into emissions. In 1999, 297 054 tons of NO_2 were generated in Sweden, 247 436 tons were exported and 404 835 tons were imported.[3] Assuming a linear relationship between the annual deposition of 454 453 tons (domestic emissions + import – export) and the annual average concentration level of 16 $\mu g/m^3$ of NO_2 in the sample of Swedish municipalities examined in the dose-response study, one $\mu g/m^3$ of NO_2 corresponds to a flow of 28 403 tons of NO_2. This is a crude approximation, but it provides an upper bound estimate of the concentration factor of NO_2.[4] Hence, the social marginal health damage per kilogram of NO_2 would be SEK 29 or € 3,1. In terms of NO_x the social marginal health damage amounts to SEK 97 per kilogram. Even if this is a conservative estimate of an optimal emission tax, it exceeds the refundable charge of SEK 40 per kilogram NO_x imposed on certain Swedish energy production plants. For comparison, a study valuing economic and ecosystem impacts of air pollutants derived an estimate of $ 3.1 per kilogram NO_x with a cost range from $0.60 to $10 per kilo (Newell 1998). However, it is difficult to determine whether our cost estimate is reasonable, and one should be cautious in drawing conclusions from the estimates as such. It is likely that several air pollutants affect health simultaneously, and it is difficult to isolate the impact of any single pollutant. On the other hand, we have focused only on health impacts and ignored ecosystem impacts such as acidification. These caveats are evident, and our valuation of social costs may underestimate or overestimate the social costs of a specific air pollutant.

Finally the total cost of the environmental problem, as well as the direct disutility from pollution which NNP should be adjusted for, will be calculated. If we had enough information about the curvature of the damage function, we could directly estimate these costs. However, since in most cases we have only a point estimate of the current damages or an estimate similar to the one derived in Table 1, an approximation of the total costs based on this information may fail with considerable margins. Typically, if the marginal damages as a function of pollution are increasing, the total costs are easily exaggerated, as can be seen in a simple illustration in Figure 1. The exaggeration becomes even more severe if the marginal damage function is convex.

Figure 1. Approximation of total damage costs when marginal damage is increasing
(The area MD(P*)xP*=A+B is an exaggeration of the real damage costs of area B. **)**



Given this reservation, our total cost estimate amounts to SEK 13 billion (454 453 tons * SEK 29 000/ton of NO_2) which is about 0.7 percent of Sweden's GDP. Of total cost, the disutility and productivity loss amounts to 61 respectively 39 percent. NNP should only be adjusted for the disutility part of the total cost (see equation 10 above), which amounts to SEK 8 billion. Of course, the success in performing cost estimation depends heavily on the monetary valuation method itself. Different components of health effects and corresponding damage provide in practice lower and upper bounds for the total cost estimates.

As a macro aggregate, NNP hides certain social costs of environmental deterioration, since such adjustments are implicit in the level of NNP. If the labor supply is affected due to increased respiratory-related restricted activity days as we have hypothesized, then the economy simply produces less annually than would be the case in the absence of pollution, but no separate downward adjustment for NNP is needed. This productivity loss was, however, estimated to be about SEK 5 billion. Thus, one caveat to be attached to such an environmentally adjusted macroeconomic indicator is that we cannot “read” all the environmental costs directly from the macro aggregate.

However, what the environmentally adjusted macro measure, or green NNP, *is* useful for is identifying the sectors of the economy that are affected: where the pollutants/emissions come from and where we can see the negative impacts. For example, since we are interested in health impacts, the physical data needed are the total amount of pollution (from all emitting sectors) and the total amount of lost working hours (in affected sectors). We have to identify the sectors involved for data collection purposes. This is particularly important if we are interested in the distribution of environmental burden and income.

4. Discussion and concluding remarks

We have presented a theoretical framework for comprehensive national accounting, which takes into account health effects of air pollution. The framework provides a tool to avoid double counting when a macro indicator is needed. A formalized objective function helps to keep track of which valuation methods are suitable for estimating direct and indirect environmental effects. In general, both the marginal costs and total costs of environmental effects can be identified in a useful way in our optimization framework.

In recent years, one of the most actively debated accounting issues has been whether mitigation costs should or should not be included in environmentally adjusted accounts (Heal and Kriström, 2001; Flores, 1999; Dasgupta et al., 1994). When analyzing air pollution and its health impacts societal mitigation costs typically consist of healthcare and medicine expenditures. Since NNP (Net National Product) is not a welfare measure per se, but measures production, or output per year, the contribution of the healthcare sector to aggregate output should be included in the accounts as is done for production in any other sector. However, the negative effects of pollutants are partly included in conventional accounts, since the healthcare sector, which treats pollution-related illnesses, crowds out investments in other production. Nevertheless, to make NNP indicate the negative effects not captured in market transactions, direct disutility from pollution, or perceived discomfort from the symptom should be included in the utility function, and NNP should be adjusted by this factor to reflect the welfare impacts.

We have derived a marginal cost-benefit rule for an optimal level of pollution given its negative health effects. The rule can be used for determining optimal regulating standards or taxes on harmful emissions. The productivity of polluting input must equal the direct disutility of pollution (perceived distress), the decreased productivity of labor (lost output) and the additional healthcare costs due to pollution (including medicines). Since the optimization rule is based on marginal social costs, we discussed the derivation of the total costs of health impacts of air pollution. It is well known that the use of marginal costs of health damage may lead to exaggeration of total costs if the marginal damage is increasing with respect to the level of pollution. This should be taken into account in the estimation of damage functions and in the interpretation of the damage cost estimates.

We have shown how the marginal social costs of health effects caused by air pollution can be empirically estimated for inclusion in environmental satellite accounts. A variety of valuation methods have been used in different contexts so that it is impossible to compare the estimated total health costs of air pollution between countries. A simultaneous adoption of more than one valuation was advocated already by Peskin and Peskin (1978). Given the valuation methods available, we have outlined a scheme for the empirical calculation of damages essential to implementing an optimal tax or regulation on air pollution causing health effects.

Finally, it should be noted that accounting adjustments for environmental effects at national, aggregate level are valid only ceteris paribus, or “at constant prices”. The adjustments for pollution damage in accounting only make sense if the changes are “fairly modest”. In addition, we do not have robust estimates of health benefits. When looking at the health impacts of environmental degradation, the focus should be on year-to-year changes rather than on comparisons with the absolute level of NNP as suggested in SEEA (p. 10-33; para 10.150). In the analysis above, human capital entered into the production function as labor inputs. However, to capture dynamic effects over time human capital should be modeled as a separate stock variable. The valuation of health stock is a challenge for future research.

Appendix

The results of the following studies were used for the figures in Table 1.

Samakovlis et al. (2002) studied the relationship between respiratory restricted activity days (RRADs) and the concentration of NO_2 in different Swedish municipalities. They used a sub-sample (N=4509) from a Swedish National Environmental Health Questionnaire (NMHE99) that could be coupled to municipality data on air quality. The data set included persons that had RRADs (n=160) during the two-week period studied. The questionnaire was sent to 15750 Swedes aged 19-81 years in 1999.

In Ready et al. (2002) six different episodes were valued, but we focused on those episodes that could be caused by air pollution. One episode (COUGH) represents a minor restricted activity episode described as one day with persistent phlegmy cough, some tightness in the chest, and some breathing difficulties. During this day, the patient cannot engage in strenuous activity, but can work and do ordinary daily activities. The other two episodes are major restricted activity episodes ("BED" and "HOSPITAL"). BED is described as three days with flu-like symptoms including persistent phlegmy cough with occasional coughing fits, fever, headache and fatigue. Symptoms are serious enough so that patient must stay home in bed for the three days. HOSPITAL is so severe that it includes admission to a hospital for treatment of respiratory distress. Symptoms include persistent phlegmy cough, with occasional coughing fits, gasping breath, fever, headache and tiredness. The patient stays in the hospital, receiving treatment for three days, followed by five days home in bed. After conversion with PPP-adjusted exchange rate and CPI correction the valuation in SEK for 1999 is 540, 1797 and 4537 for COUGH, BED and HOSPITAL respectively. For our purposes, a value of a major restricted activity day is the sum of the valuations of BED and HOSPITAL episodes divided by the number of days of restricted activity (1797+4537)/11.

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Endnotes

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[1] The Hamiltonian-based Hicksian measure of income has been actively discussed in the context of green accounting in recent years. See, e.g., Solow (1986), Mäler (1991), Hartwick (1990), Hamilton (1996), Aronsson and Löfgren (1999), Dasgupta and Mäler (1999), and Weitzman (2000). A good overview of much of this discussion is given by Heal and Kriström (2001).

[2] The theoretical model identifies all the main sources of social costs of air pollution but, as will become evident from our empirical valuation exercise in section 3, it is very difficult to estimate empirically the proportion of the output of the healthcare sector generated by treating illnesses related to air pollution.

[3] Personal communication with Christer Persson at Swedish Meteorological and Hydrological Institute. For method of calculation see Swedish Meteorological and Hydrological Institute (2001).

[4] According to Newell (1998) for ambient species with more precursors (e.g. particulates) and significant natural baselines, simple division of concentrations by total releases of each precursor should provide an upper bound estimate of the concentration factors for each precursor.

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