MODELLING THE HEALTH RELATED BENEFITS OF ENVIRONMENTAL POLICIES AND THEIR FEEDBACK EFFECTS

A CGE ANALYSIS FOR THE EU COUNTRIES WITH GEM-E3

Inge Mayeres[a]

Denise Van Regemorter[b]

Centre for Economic Studies, KULeuven

Abstract

A number of recent studies on taxation in the presence of externalities in a second-best framework consider the implications of taking into account the feedback effects of environmental quality. This paper explores by means of GEM-E3, a computable general equilibrium model for the EU countries, the importance of the feedback effects of the health related benefits from an environmental policy. The modelling framework implemented in GEM-E3 allows for three channels through which the feedback can occur: a decrease in medical expenditure, an increase in the consumers' available time and an increase of labour productivity in the production sectors. The results show that the explicit modelling of the health related effect of air pollution on consumers and producers allows for a better evaluation of the impact of environmental policies on private consumption and employment. However, in terms of global effect, the impacts of the feedback are small, compared to the standard GEM-E3 model where the health related benefits are evaluated ex-post.

Keywords: applied general equilibrium model, non-separable externalities, CO_2 tax, environment, ancillary benefits

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[a] Postdoctoral researcher of the Fund for Scientific Research – Flanders; K.U.Leuven, Centre for Economic Studies

[b] K.U.Leuven, Centre for Economic Studies

Corresponding author: Denise Van Regemorter, C.E.S., K.U.Leuven,
Naamsestraat 69, 3000 Leuven, Belgium.
Tel: +32 16 32 68 12, Fax: +32 16 32 67 96,
E-mail: Denise.VanRegemorter@econ.kuleuven.ac.be

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1. INTRODUCTION

An extensive literature has analysed optimal taxation and tax reform in the presence of externalities in a second-best framework. Most papers assume that environmental quality enters the utility function in a separable way and therefore ignore the feedback effect of environmental quality on the behaviour of the economic agents. In a number of recent studies the implications of taking into account the feedback effects are considered. These include Mayeres and Proost (1997, 2001), Schwartz and Repetto (2000) and Williams (2002, 2003).

Mayeres and Proost (1997) derive optimal tax rules in the presence of an externality with a feedback effect for an economy with distortionary taxes. The externality is assumed to enter the utility function in a non-separable way. Moreover, it leads to productivity losses in the production sectors. They show that the optimal tax on an externality generating good equals the sum of a revenue-raising component and the net social Pigouvian tax. The net social Pigouvian tax takes into account the damage imposed by the externality on consumers and producers. Moreover, it is shown that, ceteris paribus, the net social Pigouvian tax will be smaller if a higher level of the externality leads to more consumption of the taxed commodities. Williams (2002) demonstrates that the welfare effect of an externality tax consists not only of a tax interaction and revenue recycling effect, two well-known effects, but also of a benefit side tax interaction effect. Whether this last effect exacerbates or mitigates the pre-existing distortions depends on the effects of air pollution. Williams considers four possible routes through which air pollution may affect the pre-existing distortions. First, if improved air quality leads to less medical spending, this creates an income effect that reduces labour supply, thereby worsening existing distortions. Secondly, if better air quality reduces time lost to illness, the benefit side tax interaction effect is ambiguous. Thirdly, when cleaner air leads to higher labour productivity, labour supply is boosted and the existing distortions are mitigated. Finally, if a cleaner environment improves the productivity of a fixed factor, the benefits of the externality tax are reduced.

The aim of this paper is to explore by means of a computable general equilibrium (CGE) model to what extent it is important to include the feedback effects of air pollution in policy assessment. For this we use the GEM-E3 model[1], a CGE model for the European and

[1] The GEM-E3 model was built under the auspices of the European Commission (DG-RES, co-ordinator P. Valette) by a consortium involving principally NTUA, KUL, ZEW and ERASME. For a more detailed description of the model, the reader is referred to Capros et al. (1997).

World economy that covers the interaction between the economy, the energy system and the environment. In the past it has been used to evaluate the welfare impacts of several environmental policies (Capros et al., 1999). Though many CGE models aiming at evaluating environmental policies consider only the costs of environmental policy measures, in the standard GEM-E3 and some other CGE models, the benefits of environmental policies are already modelled, through an index of environmental quality that depends on emissions and provides an ex-post contribution to the consumers' welfare. In this paper we explore how the health related benefits of environmental policies can be modelled in a more realistic way in the GEM-E3 model and what are the implications for the welfare evaluation of environmental policies. We concentrate on the health related benefits as they are the largest gain from an improvement in air quality. A similar exercise for Thailand is presented by Chung-Li (2002), who explores the economy-wide repercussions of improved air quality through its effect on labour supply and medical expenditure. The main contribution of our analysis is threefold: the inclusion of more routes through which air pollution affects the economic agents, a more encompassing endogenisation of these effects, and the inclusion of the endogenous effects in a large scale and well-established CGE model.

The structure of the paper is as follows. Section 2 first presents the general characteristics of the standard GEM-E3 model, and then discusses how the model is extended to take into account a number of feedback effects of air pollution. This extension concentrates on the health impacts of air pollution. The other effects of air pollution that consist of effects on vegetation, materials and visibility are still taken into account ex-post[2]. We incorporate the impacts of air pollution on medical spending by the consumers and the public sector, on the available time of the consumers and on labour productivity. Our analysis therefore considers three of the four sources of the benefit side tax interaction effect presented by Williams (2002). We use a health production function which relates a continuous health variable to pollution and the consumption of medical care. This approach is most appropriate for modelling the morbidity effects of air pollution. A realistic treatment of the mortality impacts would require modelling health states rather than a continuous health variable (see, e.g., Freeman (2003)). Since it is less straightforward to integrate this in the GEM-E3 framework, this paper focuses on the morbidity effects, while the mortality impacts continue to be modelled in the traditional way, except for the medical costs related to them. Moreover, it is

[2] A more realistic modelling of the non-health related effects of air pollution in GEM-E3 is presented in Schmidt (2000).

not evident to translate the total marginal willingness-to-pay for a reduction in mortality as derived from stated preference studies in terms of consumption, leisure and available time, as is required in our framework.

In Section 3 the standard and modified GEM-E3 model are used to simulate the effects of a domestic CO_2 tax in the EU countries. Since a CO_2 policy has side effects on the emissions of local pollutants, the exercise enables us to explore the extent to which the welfare evaluation of a CO_2 tax is affected by incorporating the feedback effects of air pollution. It is found that taking into account the economy-wide effects of air pollution allows for a better evaluation of the impact of environmental policy on private consumption and employment. However, in terms of the global effect on the economy, the impacts turn out to be relatively small. Section 4 concludes and discusses some limitations of the paper.

2. MODELLING THE HEALTH RELATED IMPACTS OF AIR POLLUTION IN THE GEM-E3 MODEL

2.1. The standard GEM-E3 model: general characteristics

The standard version of the GEM-E3 model is an applied general equilibrium model, simultaneously representing world regions or EU countries, linked through endogenous bilateral trade. It aims at covering the interactions between the economy, the energy system and the environment. The model computes simultaneously the competitive market equilibrium under Walras' law and the optimum balance for energy demand/supply and emission/abatement. A major aim of GEM-E3 in supporting policy analysis is the consistent evaluation of distributional effects, across countries, economic sectors and agents. The burden sharing aspects of policy, such as for example energy supply and environmental protection constraints are fully analysed, while ensuring that the World/European economy remains at a general equilibrium condition.

The model has the following general features :

- Its scope is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of the agents' behaviour.
- It formulates separately the supply or demand behaviour of the economic agents that are considered to optimise individually their objective while market derived prices guarantee global equilibrium.

- It considers explicitly the market clearing mechanism and the related price formation in the energy, environment and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed.
- The model is simultaneously multinational (for the EU or the World) and specific for each country/region; appropriate markets clear European/World wide, while country/region-specific policies and distributional analysis are supported.
- Although it is global, the model exhibits a sufficient degree of disaggregation concerning sectors, structural features of energy/environment and policy-oriented instruments (e.g. taxation). The model formulates production technologies in an endogenous manner allowing for price-driven derivation of intermediate consumption and the demand for services from capital and labour. For the demand-side the model formulates consumer behaviour based on a nested Stone Geary utility function. It distinguishes between durable (equipment) and consumable goods and services. The model is dynamic, driven by the accumulation of capital and equipment. Technological progress is explicitly represented in the production functions and for each production factor.
- In its environmental module, the model evaluates the energy-related emissions of CO_2, nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOC) and particulates (PM) and translates them into concentration or deposition of pollutants, taking into account the transportation (between countries) and transformation mechanism of the pollutants; in a final step the damage generated by the concentration/deposition of pollutants is computed in physical units and monetised through a valuation function.
- The model allows to calculate the welfare effects of various environmental policies, such as taxes and various forms of pollution permits. It is also possible to consider various systems for revenue recycling.

Figure 1 gives the basic scheme of the standard version of the GEM-E3 model.

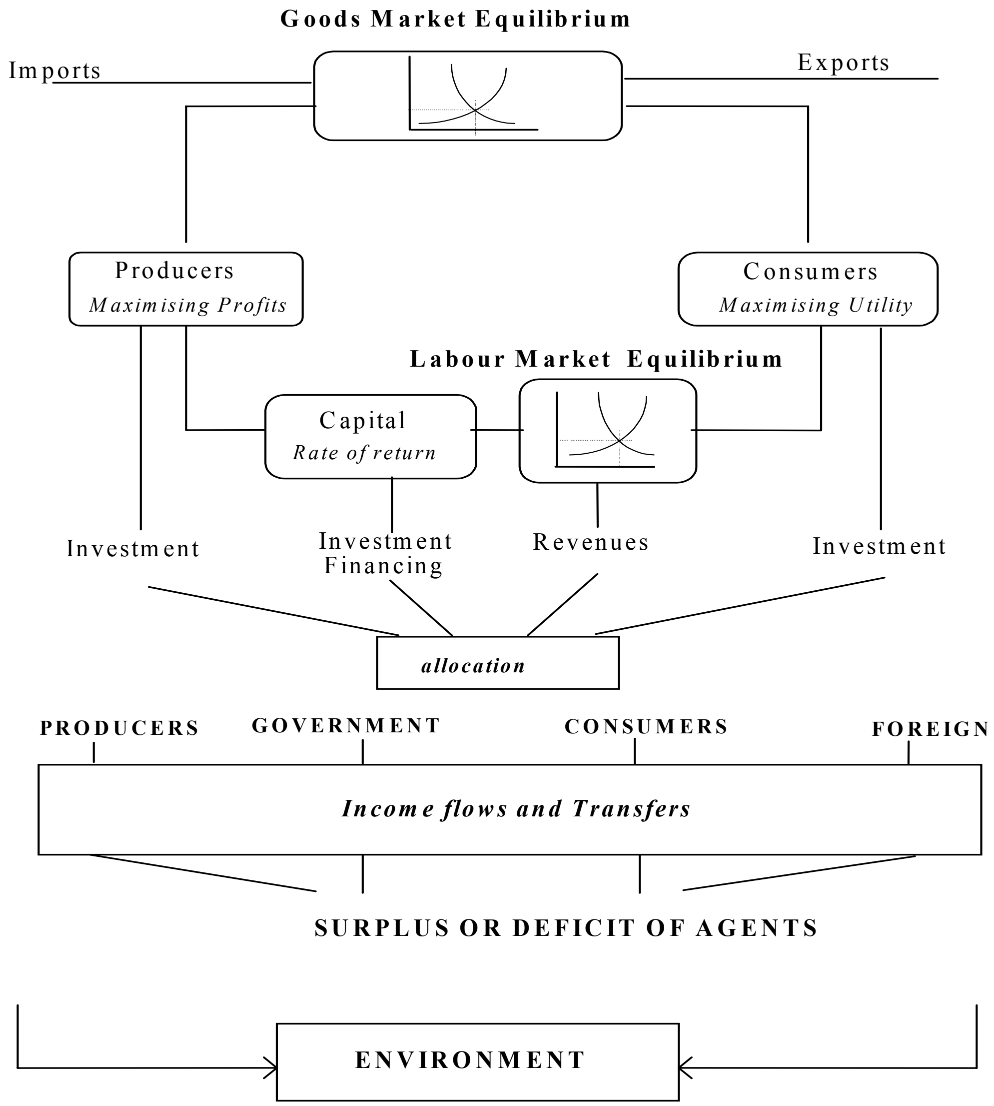

Figure 1: The standard GEM-E3 model

There are two versions of GEM-E3, GEM-E3 Europe and GEM-E3 World. They differ in their geographical and sectoral coverage, but the model specification is the same. This paper uses the GEM-E3 Europe model. The European version covers 14 EU countries (all EU countries except Luxemburg) and the rest of the world (in a reduced form) and is based on the EUROSTAT database (Input-Output tables and National Accounts data). The base year is 1995.

The standard version of GEM-E3 takes into account both the costs and benefits of environmental policy proposals. It includes an environmental quality function that depends on the emissions and that has an impact on welfare through the utility function. It is assumed that environmental quality provides a separable contribution to the consumers' welfare.

Here we present an extension of the standard GEM-E3 model. For some effects of air pollution, the feedback effect on the behaviour of the economic agents is incorporated. We focus on the feedback effects related to the health impacts of air pollution. The impact of the change in health on the consumers, production sectors and the government is modelled more realistically. Sections 2.2 to 2.5 describe how this is implemented. The non-health related effects and the mortality impacts continue to be modelled in the same way as in the standard GEM-E3 model.

2.2. The health impacts of air pollution on the consumers

In order to introduce the health related feedback effect on consumption we base ourselves on the health production function approach (for an overview of the relevant literature, see Freeman (2003)). The health production function relates a continuous health variable to exogenous (e.g., pollution) and choice variables (averting and mitigating behaviour). A health improvement corresponds with a fall in the number of days with a certain degree of impairment. We consider a deterministic framework.

To keep things simple, our presentation assumes a one-period model, while bearing in mind that GEM-E3 represents consumer behaviour by an inter-temporal model of the household sector. The representative consumer's utility function is a two-level nested LES utility function as in the standard GEM-E3 model, but with one more component linked to health.

The upper level utility function U^0 is a LES function defined over excess consumption (C-$\overline{C}$), excess leisure (l-$\bar{l}$) and excess health (H-$\overline{H}$). It is also a separable function of the ambient concentration of the different air pollutants.

$$U^0 = \alpha_1^0 \ln\left(C - \overline{C}\right) + \alpha_2^0 \ln(l - \bar{l}) + \alpha_3^0 \ln(H - \overline{H}) - \sum_{m=1}^{M} \alpha_{H,m}^0 A_m \qquad (1)$$

$\overline{C}$, $\bar{l}$ and $\overline{H}$ are subsistence levels of consumption, leisure and health. α_n^0 (n=1,…,3) are parameters of the LES function. $\alpha_{H,m}^0$ is the marginal utility of a decrease in the ambient concentration of pollutant m (m=1,...,M)($\alpha_{H,m}^0 > 0$). It reflects the separable effects of air pollution. A_m is the ambient concentration of air pollutant m w.r.t. the reference equilibrium. It is assumed to be a function of the emissions of the various air pollutants w.r.t. the reference equilibrium (EM_{po} with po=1,...,PO):

$$A_m = A_m(EM_1, ..., EM_{PO}) \ \ \forall m \qquad (2)$$

The set of M air pollutants does not only contain the PO primary pollutants, but also the secondary pollutants formed out of them in atmospheric transformation processes. The individual considers himself to be small relative to the rest of the economy and therefore takes A_m as given.

H is a health index. It is defined as follows:

$$H = H^* - \sum_m \beta_{1,m} A_m + \beta_2 MED \tag{3}$$

H^* is the exogenous level of health that can be obtained if there is no air pollution and if the consumer does not consume any medical services. $\beta_{1,m}$ and β_2 are parameters describing the impact on health of air pollution and of the consumption of medical services.

The utility function at the upper level is maximized subject to the budget constraint

$$p_C C + wl + p_{MED} MED \leq Y \tag{4}$$

taking into account equation (3). The budget constraint states that total spending on consumption, leisure and medical care cannot exceed total income Y. p_C is the consumer price of C. It is the sum of the producer price q_C and the tax t_C. $p_{MED}=q_{MED}+t_{MED}$ is the consumer price of medical services. The tax on medical services (t_{MED}) is negative, reflecting the subsidisation of medical care through the social security system in the EU countries. w is the net wage rate. Total available income is given by:

$$Y = w\left(T - \sum_{m=1}^{M} \theta_m A_m\right) + P \tag{5}$$

P is non-labour income. T stands for total available time. Due to its health effects air pollution reduces total available time by an amount θ_m per unit of change in the concentration of air pollutant m w.r.t. the reference situation. It is assumed that the time costs of bad health are borne partly by the consumers and partly by the production sectors. This reflects the institutional context in EU countries where in the case of the less severe health effects producers continue to pay workers when they are ill.

The consumer's maximisation problem gives rise to the following demand functions:

$$C = \overline{C} + \frac{\alpha_1^0 Y^d}{p_C} \tag{6}$$

$$l = \bar{l} + \frac{\alpha_2^0 Y^d}{w} \tag{7}$$

$$MED = \frac{\overline{H} - H^* + \sum_m \beta_{1m} A_m}{\beta_2} + \frac{\alpha_3^0 Y^d}{p_{MED}} \tag{8}$$

with

$$Y^d = w\left(T - \sum_m \theta_m A_m\right) + P - p_C\overline{C} - w\bar{l} - p_{MED}\frac{\overline{H} - H^* + \sum_m \beta_{1,m} A_m}{\beta_2} \qquad (9)$$

Y^d is the disposable income that can be allocated to the consumption of *C, l* and *MED*. A higher level of air pollution increases the demand for medical care, through equation (3) Secondly, it has a downward impact on the consumption of *C*, *l* and *MED* because it diminishes disposable income Y^d in two ways: it increases the subsistence level of medical consumption and it reduces total available time.

At the lower level of the nested LES function, C is allocated over twelve commodities (excl. medical care), as in the standard GEM-E3 model. The consumer is assumed to maximise

$$C = \sum_{i=1}^{12} \alpha_i^1 \ln\left(x_i - \overline{x_i}\right) \qquad (10)$$

in which x_i stands for the consumption of commodity *i* and $\overline{x_i}$ is the subsistence level. This subutility function is maximised subject to the budget constraint

$$\sum_{i=1}^{12} p_i x_i \leq Y_C \qquad (11)$$

which states that spending allocated to commodities 1 to 12 cannot exceed the budget allocated to *C* ($Y_C = p_C.C$).

2.3. The health impacts of air pollution on the production sectors

The GEM-E3 Europe model distinguishes 18 productive branches. For each branch domestic output (X_D) is produced according to a nested CES production technology, using capital, labour, electricity, fuels and materials as inputs. For simplification, the presentation here considers only one level of the nested production function and only two inputs, capital (*K*) and labour (*L*).

The extension of the GEM-E3 model takes into account that air pollution affects the number of days active people are ill. Within the institutional setting of the EU countries this is assumed to influence only partly the income of the consumers, which implies that the productivity of labour in the production sectors is affected. A rise in air pollution reduces labour productivity: more labour is needed to produce one unit of output, this increases the cost of labour and induces a substitution towards the other production factors.

For a given capital price *r* and gross wage rate w^g, the cost minimization problem of production sector *j* ($\forall j$) is given by:

$$Min \qquad rK_j + w^g L_j$$

$$s.t. \quad X_{Dj} = \left[d_{Kj}^{\frac{1}{\sigma_j}} K_j^{\frac{\sigma_j - 1}{\sigma_j}} + d_{Lj}^{\frac{1}{\sigma_j}} \left(L_j \left(1 - \gamma \left(A_1, \ldots, A_M \right) \right) \right)^{\frac{\sigma_j - 1}{\sigma_j}} \right]^{\frac{\sigma_j}{\sigma_j - 1}} \qquad (12)$$

σ_j is the elasticity of substitution. d_{Kj} and d_{Lj} are the share parameters of the CES production function. γ is the percentage of working days lost due to air pollution. It is a positive function of the ambient concentration of the M pollutants ($\partial\gamma/\partial A_m \geq 0, \ \forall\, m$).

This cost minimization problem leads to the following input demand functions for sector j:

$$K_j = X_{Dj} d_{Kj} \frac{P_{Dj}^{\ \sigma_j}}{r^{\sigma_j}} \quad \text{and} \quad L_j = \frac{X_{Dj} d_{Lj}}{1 - \gamma \left(A_1, \ldots, A_m \right)} \frac{P_{Dj}^{\ \sigma_j}}{\left(\dfrac{w^g}{1 - \gamma \left(A_1, \ldots, A_m \right)} \right)^{\sigma_j}} \qquad (13)$$

with

$$P_{Dj} = \left[d_{Kj} r^{1-\sigma_j} + d_{Lj} \left(\frac{w^g}{\left(1 - \gamma \left(A_1, \ldots, A_m \right) \right)} \right)^{1-\sigma_j} \right]^{\frac{1}{1-\sigma_j}} \qquad (14)$$

2.4. The health impacts of air pollution on the government budget

The standard GEM-E3 model distinguishes nine sources of government revenue: indirect taxes (mainly excises), value added taxes, production subsidies, environmental taxes, social security contributions and transfers, import duties, foreign transfers and revenue from government firms.

In the extension of the GEM-E3 model an increase in air pollution affects the government budget directly, through the increase in total subsidies for medical care. In addition, the government budget is affected indirectly through the impact of air pollution on the consumption of taxed commodities and labour supply.

2.5. The parameters for implementing the feedback in GEM-E3

Implementing the model requires the determination of the parameters of the utility function, the health production function and the production functions to take into account the air pollution externalities. First, we discuss the different components needed for the calibration of the consumer utility function and the production functions. Then we present briefly the environmental cost estimates provided by the European research project ExternE

(1996, 1998, 2000) and describe their decomposition into components that are relevant to our analysis. As in ExternE, the approach for the calibration derives the parameters corresponding to marginal damage, i.e. changes with respect to a reference situation.

2.5.1. Consumer utility function

The parameters of the consumer's utility function and health function related to air pollution are calibrated such that the total marginal willingness-to-pay (MWTP) of the consumers for a reduction in air pollution corresponds with the values used in ExternE and in the standard version of GEM-E3 for the ex-post evaluation.

The representative consumer's marginal WTP for a reduction in the ambient concentration of pollutant *m* ($MWTP_{Am}$) is given by

$$MWTP_{A_m} = -\frac{\partial V/\partial A_m}{\partial V/\partial Y} = w\theta_m - p_{MED}\left(\frac{(\partial H/\partial A_m)}{(\partial H/\partial MED)}\right) + \alpha^0_{H,m}Y^d \qquad (15)$$

where V is the indirect utility[3]. It is composed of three terms. The first term gives the cost to the consumer of the time lost due to illness. The second term is the marginal rate of technical substitution between pollution and medical consumption in producing a constant level of health H, multiplied by the cost of medical care for the consumer. This term reflects that the consumer is willing to pay more for a given reduction in air pollution the greater the associated improvement in health. The bid is also higher, the lower the productivity of medical care and the higher its costs. For the health production function considered in equation (3) the second term equals $p_{MED}.\beta_{1,m}/\beta_2$. The last term is the monetary equivalent of the disutility of mortality (excluding medical costs) and non-health related impacts, which are assumed to enter the utility function in a separable way. ExternE allows to compute the share of each component in the total MWTP and this is used for the calibration of θ_m and $\beta_{1,m}/\beta_2$ for GEM-E3.

The parameters α of the LES utility function are calibrated such as to keep the same labour supply elasticity in both the standard and extended GEM-E3 model.

2.5.2. Production function

The calibration of the production function is completely similar as in the standard GEM-E3 model. The parameter γ is given by the ratio between the workings days lost or gained due to the change in air pollution and the number of working days in the reference equilibrium, so it is zero by definition in the base year 1995. For the determination of the impact of air pollution on the number of working days the reader is referred to Section A.2 of the Appendix.

2.5.3. The costs of air pollution from ExternE

ExternE (1996, 1998, 2000) presents estimates for the total damage of air pollution, including the mortality, morbidity and non-health related impacts, representing the marginal willingness to pay (MWTP) for a reduction in air pollution. The study also provides information about the share of these three components. This is summarized in Table 1[4,5].

Table 1: The total damage of air pollution and the damage related to mortality, morbidity and non-health impacts

Secondary pollutant	Total damage (ECU/person/unit of ambient concentration[a])	Components of total damage		
		Mortality	Morbidity	Non-health impacts
PM_{10}, nitrates	18.92	12.64	4.48	1.80
$PM_{2.5}$, sulphates	31.14	20.97	7.37	2.80
SO_2	0.53	0.52	0.003	0.00
O_3	5.87	0.86	3.05	1.96

Source: ExternE (1996, 1998, 2000)
[a] units of ambient concentration: $\mu g/m^3$ for $PM_{2.5}$, PM_{10}, nitrates, sulphates, SO_2; 6h ppb for O_3

For the calibration of the model these values need to be decomposed further by distinguishing between the different economic agents (consumers, producers and government) and between the different components of the MWTP (i.e., time cost, non-separable health cost and separable cost component). The Appendix describes in more detail how this is done. It is assumed that non-health impacts and mortality (except for the linked medical expenditure) continue to be modelled as in the standard GEM-E3 model. Moreover, we assume that medical costs are subsidized by the government up to 80% and that approximately 42% of the time cost is borne by the consumers, while the rest is borne by the production sectors. The results are given in Table 2.

[3] It is obtained by substituting the demand functions (6) to (8) in the utility function (1).
[4] The Appendix gives more detailed information about the derivation of the health damage costs.
[5] All monetary values in the paper are given in ECU in prices of 1995.

Table 2: Detailed decomposition of the total damage of air pollution
(ECU/person/unit of ambient concentration)[a]

	PM_{10} and nitrates	$PM_{2.5}$ and sulphates	SO_2	O_3
Total damage	18.92 (100%)	31.14 (100%)	0.527 (100%)	5.87 (100%)
1) Total $MWTP_{Am}$ consumers	16.88 (89.2%)	25.28 (81.2%)	0.485 (91.9%)	5.60 (95.4%)
of which:				
a) Time costs consumers ($= w \cdot \theta_m$)	0.64 (3.4%)	1.06 (3.4%)	0.001 (0.1%)	0.13 (2.2%)
b) Non-separable health costs consumers ($= p_{MED} \cdot \beta_{1,m} / \beta_2$)	3.06 (16.1%)	2.54 (8.2%)	0.012 (2.2%)	2.74 (46.6%)
c) Separable costs consumers ($=\alpha_{H,m}^0 \cdot Y^d$)	13.18 (69.7%)	21.68 (69.6%)	0.472 (89.6%)	2.73 (46.5%)
2) Productivity losses producers	0.85 (4.5%)	1.41 (4.5%)	0.001 (0.1%)	0.18 (3.0%)
3) Medical costs government	1.20 (6.4%)	4.46 (14.3%)	0.042 (8.0%)	0.09 (1.5%)

[a] units of ambient concentration: $\mu g/m^3$ for $PM_{2.5}$, PM_{10}, nitrates, sulphates, SO_2; 6h ppb for O_3
Source: ExternE (1995-2000), Friedrich and Bickel (2001) and own assumptions

The share of the total MWTP of the consumers (as formulated by equation (15)) in the total damage ranges between 81.2% and 95.4%, depending on the pollutant that is considered. The rest of the damage is inflicted upon the production sectors and the government. The table also gives information on the value of each of the components of equation (15). Note that the share of the separable component (which does not induce any feedback) in total damage is important, reaching 70% and more except for O_3. The parameters of the utility function, the health production function and the production function are calibrated such that the values of Table 2 are obtained in the reference equilibrium. Note also that the calibration ensures that ex-ante the total MWTP remains the same in both versions of GEM-E3.

3. SIMULATION RESULTS

In this section we assess the importance of introducing these three feedback effects in the GEM-E3 model by comparing, for a scenario aiming at reaching the EU Kyoto target, the standard GEM-E3 model and the new version of the model in which the feedback effects of air pollution are incorporated.

3.1. Scenario description

We compare the two models for a domestic CO_2 tax that aims to reach the Kyoto target of the EU given the burden sharing agreement within the EU. These targets are presented in the first column of Table 3. The Kyoto target and the burden sharing agreement refer to all greenhouse gases (GHG). Since GEM-E3 considers, at this stage, only CO_2 emissions, these targets need to be translated in terms of CO_2 reductions. The EU and national CO_2 targets for 2010 have been taken from ECOFYS et al. (2001) with minor adaptations (second column of Table 3). This implicitly assumes that the relative CO_2 and other GHG abatement costs do not change with respect to the baseline. The reference scenario derived with GEM-E3 is a business-as-usual scenario in which no measures are taken to reduce CO_2 emissions. This implies a relatively important growth of CO_2 emissions by 2008-2012, the target period of the Kyoto Protocol. The last two columns of Table 3 present the reduction targets in terms of CO_2 emissions in 2010 for the two versions of the GEM-E3 model. The two model versions imply slightly different emission targets for 2010 because the extended GEM-E3 model takes into account the feedback effects of the growth in the emissions of local air pollutants (NO_x, SO_2, VOC and PM) that is observed under the business-as-usual scenario. For most countries and the EU in total this leads to a slightly smaller reduction target than in the absence of the feedback effects. In five countries the feedback effects imply that CO_2 emissions should be reduced by more than in the standard GEM-E3 model.

Table 3: Kyoto reduction targets for 2010

	All GHG (burden sharing agreement)	CO_2 (ECOFYS study)	CO_2 (ECOFYS study)	CO_2 (ECOFYS study)
	% change w.r.t. 1990	% change w.r.t. 1990	% change w.r.t. 2010; GEM-E3 baseline without feedback	% change w.r.t. 2010; GEM-E3 baseline with feedback
Austria	-13.0	-18.2	-31.3	-31.6
Belgium	-7.5	-6.9	-19.0	-19.0
Germany	-21.0	-19.4	-5.4	-5.7
Denmark	-21.0	-23.2	-28.4	-28.5
Finland	0.0	4.8	-4.4	-4.3
France	0.0	6.8	-9.8	-9.3
Greece	25.0	37.2	-5.5	-5.6
Ireland	13.0	20.7	-25.4	-25.2
Italy	-6.5	-6.1	-27.4	-27.3

The Netherlands	-6.0	4.3	-15.1	-14.6
Portugal	27.0	49.6	-11.2	-10.8
Spain	15.0	26.7	-23.2	-22.9
Sweden	4.0	4.5	-7.0	-7.0
UK	-12.5	-9.7	-0.9	-1.2
EU	-8.0	-4.9	-12.7	-12.6

The CO_2 tax is implemented at country level in the target period 2008-2012 with the CO_2 reduction target for each country given by the last two columns in Table 3, depending on the model version. Budget neutrality is obtained by using the revenues generated by the CO_2 tax to reduce the social security contributions. We consider only one policy instrument as our objective is to evaluate the impact of modelling the feedback effects, rather than to compare policy instruments.

3.2. The Scenario results

Table 4 presents the domestic CO_2 taxes that are required to reach the Kyoto target. As can be expected, the CO_2 tax is higher in the model with feedback for those countries where the feedback effects imply a higher reduction target in 2010 (cf. Table 3). This reflects the fact that the marginal CO_2 abatement costs increase with the abatement levels. At the EU level the marginal CO_2 abatement cost and therefore the CO_2 tax is higher in the model with feedback. Table 4 shows that the social security contributions can on average be reduced by more in the model with feedback. This is made possible partly by the higher CO_2 tax revenues, but also by other factors which will be discussed in more detail below. The lower social security contributions play a role in the increase in the EU average real wage rate which is evident in Table 4.

Table 4: Policy variables and relative prices

	Model without Feedback				Model with Feedback			
	CO_2 domestic tax	Reduction of social security rate	Real wage rate	Terms of trade	CO_2 domestic tax	Reduction of social security rate	Real wage rate	Terms of trade[6]
	(ECU95/ tonne CO_2)	% change in 2010 w.r.t. baseline			(ECU95/ tonne CO_2)	% change in 2010 w.r.t. baseline scenario		
Austria	147.5	5.79	1.71	0.58	149.5	5.93	1.78	0.59
Belgium	24.1	2.09	1.18	0.23	24.3	2.24	1.27	0.22
Germany	9.9	0.63	0.35	0.30	10.6	0.78	0.44	0.29
Denmark	64.2	3.24	1.38	0.46	64.6	3.30	1.42	0.46
Finland	1.7	0.11	0.25	0.11	1.7	0.12	0.26	0.12
France	40.0	1.88	0.93	0.00	37.8	1.81	0.93	0.00
Greece	4.7	1.29	1.03	0.33	4.9	1.35	1.08	0.35
Ireland	46.5	4.37	1.95	0.18	46.1	4.36	1.95	0.18
Italy	166.1	11.70	5.66	0.70	166.1	11.81	5.73	0.69
The Netherlands	28.2	2.13	1.08	-0.03	27.0	2.19	1.14	-0.04
Portugal	13.3	1.76	1.19	0.08	12.8	1.82	1.25	0.07
Spain	60.1	5.16	2.32	0.98	59.4	5.16	2.34	0.97
Sweden	7.9	0.40	0.33	0.04	8.0	0.41	0.35	0.05
UK	1.2	0.06	0.47	0.32	1.5	0.11	0.52	0.34
EU	37.3	2.99	1.14	1.78	40.2	3.06	1.20	1.79

Table 4 also presents the terms of trade effect. Previous research indicates that this is an important element in the explanation of the double dividend that can be realised by CO_2 taxes in the EU (see, for example, de Mooij (1999) and Proost and Van Regemorter (1998)). However, in our exercise it does not play a major role in explaining the difference in impacts between the two models, as the terms of trade effect hardly changes between the two versions of the GEM-E3 model.

Table 5 summarizes the impact of the domestic CO_2 taxes on the emissions of NO_x, SO_2, VOC and PM at the EU level. The difference between the two models is the result of the different CO_2 reduction targets that are imposed.

6 For the individual countries the terms of trade are computed relative to all trading partners, whereas for the EU as a whole the terms of trade are computed relative to outside EU trading partners.

Table 5: The impact of the domestic CO_2 tax on local pollutant emissions (% change in 2010 w.r.t. the baseline)

	Model without Feedback				Model with Feedback			
	NO_x	SO_2	VOC	PM	NO_x	SO_2	VOC	PM
EU	-14.4	-18.3	-9.6	-18.9%	-14.3	-18.4	-9.5	-19.0

The feedback effect of the changes in the local air pollutants, as modelled in this paper, goes through three main channels:

- a decrease in medical expenditure: the reduction in the emissions of local air pollutants induces a shift of consumption towards other goods and leisure, and eases the budget constraint of the government;
- an increase in the consumers' available time: this induces an increase in both labour supply and leisure demand through the generalized income effect;
- an increase of labour productivity in the production sectors: this limits the price increase due to the CO_2 tax, which reinforces the beneficial revenue recycling effect of the tax.

Table 6 provides more insight in the importance of these effects. It shows that the macro-economic impacts of the domestic CO_2 taxes do not change a lot if the feedback effect of air pollution is modelled. This can be explained by two factors. First of all, the local benefits of the CO_2 taxes are already very limited in the GEM-E3 model without feedback. Secondly, only approximately 30% of the external air pollution costs of the main local air pollutants ($PM_{2.5}$, PM_{10}, sulphates and nitrates) is associated with a feedback effect in our set-up.

The benefits of the feedback effect are translated principally in terms of an increase in private consumption, whereas the final impact on the labour market remains similar in both model versions. However, while there is no differential impact on employment, the real wage rate increases more in the model with feedback. There is therefore an increase in the income available for consumption which explains why private consumption is increased by more in the extended model version.

Table 6 also shows that the local benefits are smaller in the model with feedback. This is because part of the ex-post air pollution costs of the standard GEM-E3 model are now included directly in the utility and production functions.

Table 6: The macro-economic impacts of the domestic CO_2 tax

	Model without Feedback				Model with Feedback			
	Gross Domestic Product	Employment	Private consumption	Local benefits	Gross Domestic Product	Employment	Private consumption	Local Benefits
	(% change in 2010 w.r.t. baseline)			(% of GDP)	(% change in 2010 w.r.t. baseline)			(% of GDP)
Austria	-0.44	0.84	0.08	0.09	-0.45	0.85	0.09	0.07
Belgium	-0.05	0.25	0.55	0.19	-0.05	0.26	0.58	0.14
Germany	-0.10	-0.03	0.37	0.15	-0.09	-0.02	0.41	0.11
Denmark	-0.26	0.17	0.69	0.06	-0.26	0.16	0.72	0.04
Finland	-0.09	-0.12	0.43	0.01	-0.09	-0.13	0.45	0.01
France	0.07	0.28	0.27	0.06	0.06	0.26	0.29	0.04
Greece	-0.04	0.15	0.44	0.04	-0.04	0.16	0.46	0.03
Ireland	-0.15	0.45	1.13	0.04	-0.15	0.43	1.14	0.03
Italy	-0.55	2.15	-0.99	0.14	-0.55	2.15	-0.97	0.09
The Netherlands	-0.08	0.30	0.06	0.16	-0.08	0.29	0.11	0.11
Portugal	0.04	0.19	0.67	0.10	0.03	0.20	0.70	0.07
Spain	-0.15	0.77	0.66	0.14	-0.16	0.75	0.69	0.09
Sweden	-0.04	-0.09	0.45	0.02	-0.04	-0.09	0.47	0.01
UK	-0.15	-0.24	0.67	0.04	-0.16	-0.24	0.72	0.03
EU	-0.14	0.40	0.25		-0.14	0.40	0.28	

The use of a different utility function also implies that a comparison of the welfare levels between the two model versions is not justified. We find that in both model versions the domestic CO_2 taxes lead to a total welfare gain (including environmental benefits) at EU level, though specific countries show a welfare loss and this in both model versions. The welfare gain at EU level equals 0.13% in the model without feedback and 0.11% in the model with feedback. However, it should be borne in mind that it would be incorrect to compare these two figures.

4. CONCLUSIONS

The paper examines the impact of modelling the feedback of the health related benefits from an environmental policy on the policy evaluation. The modelling framework implemented in GEM-E3, a CGE model for Europe, allows for three channels through which the feedback can occur: a decrease in medical expenditure, an increase in the consumers' available time and an increase of labour productivity in the production sectors. The results show that the explicit modelling of the health related effect of air pollution on consumers and producers allows for a better evaluation of the impact of environmental policies on private consumption and employment. However, in terms of global effect, the impacts of the feedback are small, compared to the standard GEM-E3 model where the health related benefits are evaluated ex-post. Accounting for the feedback effect induces a shift of the impact from the ex-post term to the other components of utility, rather than a change in the magnitude of the total impact.

In terms of policy evaluation, one might conclude that using damage costs as derived by ExternE without considering the feedback effects, can give a good approximation of a policy impact, as these effects are negligible. However, before reaching such a conclusion, it is important to note that our findings clearly depend on the ExternE figures and other assumptions that we made for modelling the feedback effects. All of these are subject to uncertainty. This is the case for example, for the transport and chemical transformation processes of pollutants, the dose-response relationships and the valuation of the health effects. In addition, the mortality impact remains separable, except for the associated medical expenditure. However, we would expect the feedback on the economy from a decrease of the mortality rate linked to local pollution to be small as it mainly benefits non-active people. Moreover, the framework developed here for the morbidity effect is not appropriate for mortality, for which it might be difficult to translate the total MWTP as derived from stated preference studies in terms of consumption, leisure or available time. Finally, we would like to point out that our conclusions are dependent on the institutional setting in Europe.

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APPENDIX

A.1. Computation of the health related damage

To illustrate how the health related damages in Table 1 are derived, we look at the case of ozone (O_3). From the ExternE study we know that the dose-response functions for O_3 are as follows:

Table A.1: Dose-response relationship for tropospheric ozone

Impact category	Receptor	Exposure-response slope[a]
Acute mortality	Entire population	0.059%
Morbidity - Respiratory hospital admissions	Entire population	$3.54\ 10^{-6}$
- Minor restricted activity days	Adults (80% of population)	$9.76\ 10^{-3}$
- Asthma attacks	Asthmatics (3.5% of population)	$4.29\ 10^{-3}$
- Symptom days	Entire population	0.033

Source: ExternE (1996, 1998, 2000)

[a] The exposure response slope has units of cases/(year-person-µg/m^3) except for mortality which is expressed as percentage increase per µg/m^3.

The dose-response functions are converted into cases/(year-person-6h ppb) by multiplying them by 2. The dose-response functions for morbidity are then all expressed in cases/(year-1000persons-6h ppb) for the entire population taking into account the receptor share in total population. The dose-response function for acute mortality is expressed in the same units by using the assumption that the baseline mortality rate is 0.99%. The resulting exposure-response slopes are combined with the damage values from ExternE in order to obtain the total health related marginal damage per person.

Table A.2: Derivation of the health related marginal damage - O_3 concentrations

Impact category	Exposure-response slope (cases/(year-1000persons-6hppb))	Damage (ECU/case)	Marginal damage of O_3 pollution (ECU/(year-person-6h ppb)
Acute mortality	0.01	73500	0.86
Morbidity			3.05
- Respiratory hospital admissions	0.01	1600	0.01
- Minor restricted activity days	15.62	37.1	0.58
- Asthma attacks	0.30	33.5	0.01
- Symptom days	66	37.1	2.45
Total health related damage			3.91

Source: own calculations based on ExternE (1995-2000)

A similar methodology is used to derive the marginal damage of the other pollutants. The first column of Table A.3 gives the resulting health related marginal damage for all pollutants considered in our study.

Table A.3: Air pollution damages and the impact of air pollution on working days

	Marginal Damage (ECU95/ person/unit of ambient concentration)	Cases per 1000 active persons per unit of ambient concentration	Working days lost per case	Working days lost per 1000 active persons per unit of ambient concentration
PM_{10}	**17.12**			**64.62**
Chronic and acute mortality	*12.64*			
Acute morbidity	*2.32*			*63.02*
Respiratory hospital admissions	0.00	0.001	8.50	0.09
Congestive heart failure	0.02			
Cerebro-vascular hospital admissions	0.04	0.003	40.50	1.08
Restricted activity days	1.88	13.20	0.50	52.80
Bronchodilator usage				
- asthmatic children	0.02			
- asthmatic adults	0.15	3.01	0.18	4.29
Cough				
- asthmatic children	0.03			
- asthmatic adults	0.16	3.11	0.18	4.42
Wheeze				
- asthmatic children	0.01			
- asthmatic adults	0.01	1.13	0.04	0.35
Chronic morbidity	*2.16*			*1.60*
Chronic bronchitis				
- adults	1.99	0.01	15.40	1.60
- children	0.07			
Chronic cough in children	0.09			
SO_2	**0.52**			**0.10**
Acute mortality	*0.52*			
Acute morbidity	*0.00*			*0.10*
Respiratory hospital admissions	0.00	0.001	8.50	0.10

Source: ExternE(1996, 1998, 2000) and own assumptions

Table A.3(continued):
Air pollution damages and the impact of air pollution on working days

	Marginal Damage (ECU/ person/unit of ambient concentration)	Cases per 10^3 active persons per unit of ambient concentration	Working days lost per case	Working days lost per 10^3 active persons per unit of ambient concentration
$PM_{2.5}$	**28.34**			**108.29**
Chronic and acute mortality	*20.97*			
Acute morbidity	*3.90*			*105.75*
Respiratory hospital admissions	0.01	0.002	8.50	0.16
Congestive heart failure	0.03			
Cerebro-vascular hospital admissions	0.06	0.006	40.50	1.80
Restricted activity days	3.16	22.18	0.50	88.70
Bronchodilator usage				
- asthmatic children	0.03			
- asthmatic adults	0.26	5.03	0.18	7.15
Cough				
- asthmatic children	0.05			
- asthmatic adults	0.26	5.17	0.18	7.36
Wheeze				
- asthmatic children	0.01			
- asthmatic adults	0.02	1.87	0.04	0.57
Chronic morbidity	*3.47*			*2.54*
Chronic bronchitis				
- adults	3.17	0.02	15.43	2.54
- children	0.12			
Chronic cough in children	0.18			
O_3	**3.91**			**18.16**
Acute mortality	*0.86*			
Acute morbidity	*3.05*			*18.16*
Respiratory hospital admissions	0.01	0.01	8.50	0.32
Minor restricted activity days	0.58	10.31	0.20	16.25
Change in asthma attacks	0.01	0.20	1	1.59
Symptom days	2.45	43.56	0	0.00

Source: ExternE (1996, 1998, 2000) and own assumptions

A.2. Decomposition of the damage

For the calibration of the GEM-E3 model the total damage of the air pollutants needs to be decomposed further into 5 components: (i) the time costs borne by the production sectors, (ii) the time costs borne by the consumers, (iii) the non-separable health costs of the consumers, (iv) the separable costs for the consumers and (v) the medical costs paid by the government. This decomposition is presented in Table A.4.

Computation of the time cost

The last three columns of Table A.3 summarise the calculation of the impact of air pollution on working days. This is done for the morbidity impacts only. It is assumed that the working population accounts for 66% of the total population. We also assume that on average a restricted activity day (RAD) leads to a loss of 0.5 working days per case. For the other morbidity effects the number of lost working days is obtained as follows:

$$\text{working days lost per case for event } n = 0.5 * (\text{cost of illness of event } n) / (\text{cost of illness of RAD})$$

For chronic bronchitis the resulting figure is divided by the remaining number of years, which is taken to be 35. The value of the productivity loss of the firms is then calculated by multiplying the total number of working days lost with the average gross wage rate. γ is computed by dividing the total number of working days lost due to air pollution per person by the total number of working days per person.

In addition to the working days lost, the consumer's available time is also reduced. It is assumed that per lost working day of 8 hours, the consumer loses on average 6 additional hours of leisure time.

Value of other components

The value of the other components of the air pollution damage is taken from ExternE (1996, 1998, 2000) and Friedrich and Bickel (2001), except in the case of medical costs related to mortality. They are assumed to account for 10% of the total marginal willingness-to-pay for the reduction of mortality.

To compute the medical costs paid by the government it is assumed that a government subsidy of 80% exists for medical care.

Table A.4: The decomposition of the total marginal damage of the pollutants
(ECU/unit of ambient concentration)[a]

	Effect no.	PM_{10} and nitrates	$PM_{2.5}$ and sulphates	SO_2	O_3
Total damage		18.92	31.14	0.53	5.87
Non-health related damage	(1)	1.80	2.80	0.00	1.96
Mortality		12.64	20.97	0.52	0.86
Pure MWTP	(2)	11.38	18.87	0.47	0.77
Medical costs		1.26	2.10	0.05	0.09
Consumers	(3)	*0.25*	*0.42*	*0.01*	*0.02*
Government	(4)	*1.01*	*1.68*	*0.04*	*0.07*
Morbidity		4.48	7.37	0.003	3.05
Pure MWTP	(5)	2.76	1.42	0.002	2.71
Medical costs		0.24	3.48	0.000	0.03
Consumers	(6)	*0.05*	*0.70*	*0.000*	*0.01*
Government	(7)	*0.19*	*2.78*	*0.000*	*0.02*
Time costs		1.48	2.47	0.001	0.31
Consumers	(8)	*0.64*	*1.06*	*0.001*	*0.13*
Production sectors	(9)	*0.85*	*1.41*	*0.001*	*0.18*
Decomposition GEM-E3					
Time costs consumers	= (8)	0.64	1.06	0.001	0.13
Non-separable health costs consumers	= (3)+(5)+(6)	3.06	2.54	0.012	2.74
Separable costs consumers	= (1)+(2)	13.18	21.68	0.472	2.73
Productivity losses producers	= (9)	0.85	1.41	0.001	0.18
Medical costs government	= (4)+(7)	0.20	4.46	0.042	0.09

[a] Units of ambient concentration: µg/m^3 for $PM_{2.5}$, PM_{10}, nitrates, sulphates and SO_2; 6h ppb for O_3
Source: ExternE (1996, 1998, 2000), Friedrich and Bickel (2001) and own assumptions