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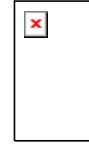
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MODELLING THE HEALTH RELATED BENEFITS OF ENVIRONMENTAL POLICIES A CGE MODEL FOR THE EU-15 COUNTRIES

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Preliminary version

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1. INTRODUCTION

The aim of this paper is to explore how the health related benefits of environmental policies can be modelled in a more realistic way in the GEM-E3 model, a computable general equilibrium (CGE) model for the European and World economy. The model 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)).

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A lot of CGE models that aim to evaluate environmental policies consider only the costs of environmental policy measures. The incorporation of the benefits of environmental policies has received less attention. A number of models include an index of environmental quality that depends on emissions and that has an effect on economic welfare either directly through the utility functions and/or indirectly through the productivity of labour, capital or other inputs in the production sectors. As regards the direct impact through the utility functions, two modelling approaches are used. The first approach introduces environmental quality as providing a separable contribution to the consumers' welfare. This is also the approach taken in the standard GEM-E3 model. In the second approach, the separability assumption is relaxed. In this paper we investigate how this can be done in the GEM-E3 model and what are the implications for the welfare evaluation of environmental policies. A theoretical discussion of the implications for the optimal externality of relaxing the separability assumption is given in Mayeres and Proost (1997), Schwartz and Repetto (2000) and Williams (2000).

The structure of this 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, i.e. the impact of air pollution on the behaviour of the economic agents. This extension concentrates on the health impacts of air pollution. As a first step, the approach is applied to the morbidity effects of air pollution and tries to model these effects on the consumers, production sectors and the government more realistically. The other effects of air pollution that consist of the mortality impacts and the effects on vegetation, materials and visibility are still assumed to enter preferences in a separable way.

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Section 3 presents simulation results with the modified GEM-E3 model. A comparison is made of two environmental policies that allow reaching the Kyoto target for the European Union. It is shown that it is important to model the impact of morbidity on the production sectors, while including the health effects on consumers and the government budget affects the results less. Including the effects on production substantially changes the welfare impact of the environmental policies and affects the ranking of the two policy instruments considered in the paper. 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 model¹ 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 the Walras law and determines 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.

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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 agent's 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 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 services from capital and labour. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services. The model is dynamic, driven by accumulation of capital and equipment. Technology 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 CO₂, NO_x, SO₂, VOC and particulates and translates them into concentration or deposition of pollutants, taking into account the transportation (between countries) and

¹ The GEM-E3 model was built under the auspices of the European Commission (DG-RESI, 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).

transformation mechanism of the pollutants; in a final step the damage generated by the concentration/deposition of pollutants is computed in physical units and valued through a valuation function.

- The model allows calculating 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

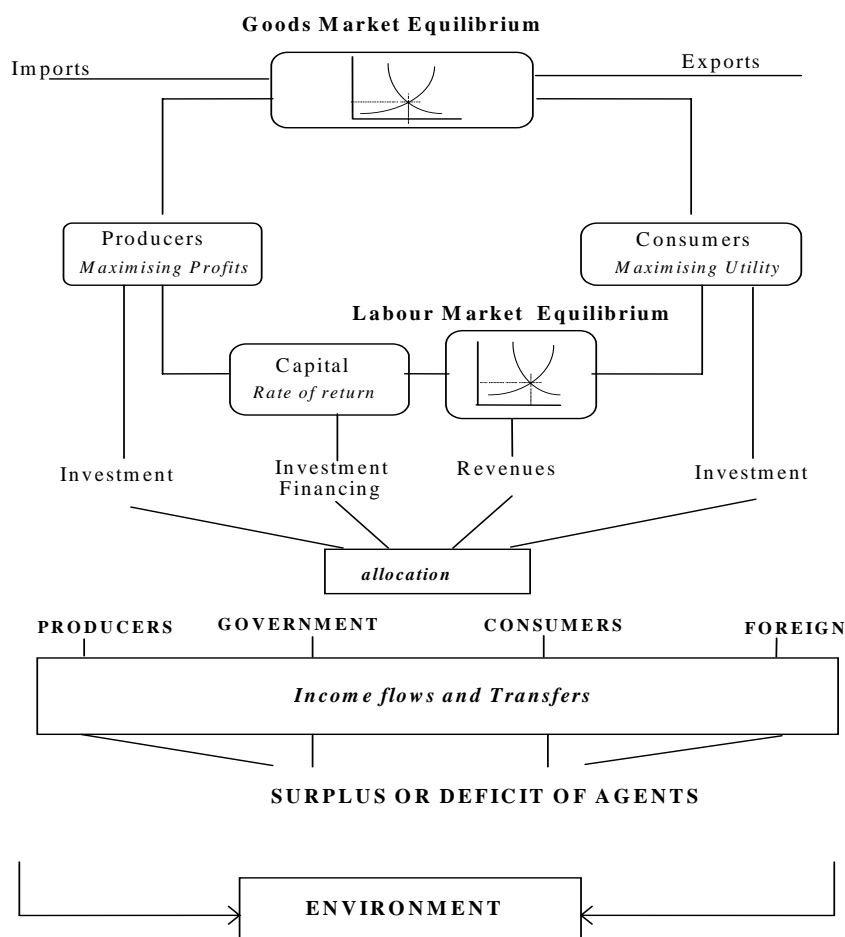


Figure 1: The standard GEM-E3 model

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. They use the GAMS software and are written as a mixed-complementarity problem solved by using the PATH algorithm. This paper uses the GEM-E3 Europe model. The European version covers 14 EU countries and the ROW (in a reduced form) and is

based on the EUROSTAT database (IO 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 economic 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. The separability assumption is relaxed for some effects of air pollution. The feedback effect of air pollution is modelled, allowing for its impact on the behaviour of the economic agents. We focus on the feedback effects related to the health impacts of air pollution, and more particularly those related to morbidity. The impact of the change in morbidity on the consumers, production sectors and the government is modelled more realistically. Sections 2.2 to 2.5 describe how this is done. For the mortality effects and the non-health related effects² we continue to assume that they enter preferences in a separable way.

2.2. The health impacts of air pollution on the consumers

In order to introduce the morbidity related feedback effect on consumption we base ourselves on the health production function approach [for an overview of the relevant literature, see Freeman (1993)]. The health production function relates a continuous health³ 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. It is also assumed that a change in the exogenous and choice factors in a certain period has an effect on health in the same period. Latent health effects are therefore not considered.

To keep things simple our presentation assumes a one-period model, while bearing in mind that GEM-E3 represents household behaviour by an intertemporal model of the household sector. The representative consumer's utility function is a two-level nested LES utility function. The upper level utility function U^0 is similar as in the standard GEM-E3 model without feedback effects. It is an LES function defined over excess consumption ($C - \bar{C}$) and excess leisure ($l - \bar{l}$) and is a separable function of the ambient concentration of the different air pollutants.

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

α_1^0 and α_2^0 are parameters of the LES function. $\alpha_{H,m}^0$ is the marginal disutility of the ambient concentration of pollutant m ($m=1, \dots, M$) ($\alpha_{H,m}^0 < 0$). It reflects the separable health effects and the non-health-related effects of air pollution. A_m is the change in the

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

³ An alternative approach considers different health states rather than a continuous health variable. While the latter approach is more appropriate for the acute morbidity effects, the former approach is better for modelling the mortality and chronic morbidity effects. In our paper the continuous health variable also includes chronic morbidity effects. While not perfect, this is justifiable because the chronic morbidity effects are relatively small compared to the acute morbidity effects (see Appendix A).

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ambient concentration of air pollutant m w.r.t. the reference equilibrium. A_m is assumed to be a function of the change in emissions of the various air pollutants w.r.t. the reference equilibrium (EM_{po} with $po=1,...,PO$):

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

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 and therefore takes A_m as given.

The consumers is assumed to maximise his utility function subject to the budget constraint:

$$p_C C + w l \leq Y \quad (3)$$

p_C is the price index of C , w is the after tax wage rate. Y is defined as:

$$Y = wT + P \quad (4)$$

T stands for total available time and P is non-labour income. Maximising U^0 subject to the budget constraint (3) gives rise to the following demand function for aggregate consumption:

$$C = \bar{C} + \frac{\alpha_1^0}{p_C} (Y - p_C \bar{C} - w \bar{l}) \quad (5)$$

A similar expression is obtained for l .

2.2.1. The lower level of the utility function

The health effects related to acute and chronic morbidity are introduced at the lowest level (level 1) of the utility function where total consumption C is allocated over the various commodities. The consumer is assumed to maximise the following sub-utility function:

$$C = \sum_{i=1}^6 \alpha_i^1 \ln(x_i - \bar{x}_i) + \alpha_H^1 \ln(H - \bar{H}) \quad (6)$$

in which x_i stands for the consumption of commodity i and \bar{x}_i is the subsistence level.

The α_i^1 and α_H^1 are parameters of the LES function. H is the change in morbidity related health compared to the reference equilibrium. H is defined as follows:

$$H = H^* - \sum_{m=1}^M \beta_{1,m} A_m + \beta_2 x_7 \quad (7)$$

H^* is the exogenous change in the level of health that can be obtained when there is no change in air pollution w.r.t. the reference equilibrium and the consumer does not consume any medical services. x_7 is the consumption of medical services by the consumers. $\beta_{1,m}$ and β_2 are parameters of the household production function of H . The utility function at level 1 is maximised subject to the budget constraint, which states that spending allocated to commodities 1 to 7 cannot exceed the budget allocated to the consumption of the commodities ($Y_C = p_C C$).

$$\sum_{i=1}^7 p_i x_i \leq Y_C \quad (8)$$

p_i is the consumer price of commodity i . It is the sum of the producer price q_i and the tax t_i . In the case of medical services, the tax is negative, reflecting the subsidisation of medical care through the social security system in EU countries.

Note that H is assumed not to affect total time available T . Nor does it influence the consumer's income directly in another way. The individuals continue to be paid by the firms, which is a realistic assumption for European countries in the case of morbidity impacts. This implies that the impact of air pollution on the firms needs to be modelled, as will be described in Section 2.3.

Maximising C subject to the budget constraint, taking into account (7), gives rise to the following demand functions, for a given budget of Y_C to be devoted to the consumption of the commodities:

$$x_i = \bar{x}_i + \frac{\alpha_i^1}{p_i} Y_C^d \quad (9)$$

$$x_7 = \frac{\bar{H} - H^* + \sum_{m=1}^M \beta_{1,m} A_m}{\beta_2} + \frac{\alpha_H^1}{p_7} Y_C^d \quad (10)$$

where Y_C^d is the disposable income that can be allocated to the consumption of commodities 1 to 7:

$$Y_C^d = Y_C - \sum_{i=1}^6 p_i x_i - p_7 \left(\frac{\bar{H} - H^* + \sum_{m=1}^M \beta_{1,m} A_m}{\beta_2} \right) \quad (11)$$

Ceteris paribus, a higher level of air pollution increases the demand for medical care (commodity 7), since it increases the subsistence level of this commodity (as is shown in the first term on the RHS of (10)). Secondly, it has a downward impact on the consumption of all commodities because it diminishes the income available for the excess consumption of the commodities.

The model is equivalent to a model in which the lower level utility function is an LES function defined over, inter alia, the excess demand for medical care, where the subsistence level of medical care is assumed to be $(\bar{H} - H^* + \sum_m \beta_{1,m} A_m) / \beta_2$. This is also similar to the approach taken by Espinosa and Smith (1995).

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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 production is represented through a nested separability scheme involving capital, labour, electricity, fuels and materials.

The extension of the GEM-E3 model takes into account that air pollution affects the number of days that active people are ill. As was discussed in Section 2.2, morbidity is assumed not to influence the income of the consumers. This means 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.

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 calibration of the model

The parameters related to air pollution of the consumer's utility function are calibrated such that the marginal willingness-to-pay (WTP) for a reduction in air pollution corresponds with the value found in the literature. In general the marginal WTP for a reduction in the ambient concentration of pollutant m can be written as:

$$MWTP_{A_m} = \frac{\alpha_{H,m}^0}{\lambda} - p_7 \frac{(\partial H / \partial A_m)|_{x_7}}{\partial H / \partial x_7} \quad (12)$$

The first part on the RHS is the marginal WTP related to mortality and non-health related effects of air pollution. The second part is related to the morbidity effects. $(\partial H / \partial A_m)|_{x_7} / (\partial H / \partial x_7)$ is the marginal rate of technical substitution between pollution and medical consumption in producing a constant level of H . The individual is willing to pay more for a given reduction in air pollution the greater the associated improvement in morbidity related health. The bid is also higher the lower the productivity of medical care and the higher its costs. The marginal WTP can be calculated using (12) provided that the health production function is known. However, we know only the dose-response relationship, not the health production function⁴. We therefore need to reformulate (12). This is done in equation (13). The first term is the same as in equation (12). The second and third term give the observed reduction in the costs of medical care and the monetary equivalent of the disutility of illness, respectively. To compute dH/dA_m the dose-response relationship can be used.

$$MWTP_{A_m} = \frac{\alpha_{H,m}^0}{\lambda} + p_7 \frac{\partial x_7}{\partial A_m} - \frac{\partial U^0 / \partial H}{\lambda} \frac{dH}{dA_m} \quad (13)$$

$\alpha_{H,m}^0 / \lambda$ is the marginal WTP for a reduction in the ambient concentration of pollutant m . λ is the marginal utility of income. The WTP includes only the mortality and non-health

⁴ The key difference between the health production function and the dose-response relationship lies in the treatment of x_7 . In the health production function it is treated as a choice variable while in the dose response relationship H is specified as a function of a variety of variables all of which are treated as exogenous [see Gerking and Stanley (1986)].

related costs of air pollution. ExterneE (1998) gives the total marginal WTP⁵, including mortality, morbidity and non-health related impacts. The mortality costs account for the following share of the total health related marginal WTP found in ExterneE⁶:

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Table 1: The health damage of air pollution and the share of mortality related damage

Secondary pollutant	total health related marginal WTP (EURO/unit of ambient concentration ^a)	Share of the mortality costs in the total health related marginal WTP
PM ₁₀ , nitrates	19.89	79%
PM _{2.5} , sulphates	32.89	79%
SO ₂	0.54	97%
O ₃	1.54	56%

^a units of ambient concentration: $\mu\text{g}/\text{m}^3$ for PM_{2.5}, PM₁₀, nitrates, sulphates, SO₂; 6h ppb for O₃

Source: ExterneE (1998)

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dH/dA_m is the full impact of air pollution on morbidity. It is calibrated on the basis of the morbidity related dose response relationships found in ExterneE (see Appendix A).

As regards the valuation of the morbidity effects we assume that the pure marginal WTP accounts for 50% of the total marginal WTP calculated by ExterneE⁷. The other 50% account for the pure economic costs, which we assume to correspond with the medical costs.

$\alpha_{H,m}^1$ is calibrated such that $(\partial U^0 / \partial H) / \lambda$ reflects the pure marginal WTP for a reduction in the morbidity effects. $\partial x_7 / \partial A_m$ is calibrated on the basis of the ExterneE dose-response relationships.

A_m and EM_{po} are by definition equal to zero in the reference equilibrium since they give the change in the ambient concentration and emissions w.r.t. the benchmark. It is also assumed that H^* and \bar{H} are zero.

In order to calculate the effect on labour productivity, we need to know the effect of a change in the ambient concentrations on the number of days that active people are ill. ExterneE provides the effect of a change in air pollution on morbidity cases. By associating each morbidity effect with a number of working days lost (see Appendix A), we get the values in Table 2.

⁵ Appendix A gives more detailed information on the health damage costs.

⁶ All monetary values in the paper are given in EURO in prices of 1995.

⁷ ExterneE estimates the total marginal WTP as 2 to 3 times the cost of illness.

Table 2: The impact of air pollution of working days

Secondary pollutant	Working days lost per 1000 active persons per unit of ambient concentration ^a change
PM _{2.5} , sulphates	17.25
PM ₁₀ , nitrates	28.88
SO ₂	0.03
O ₃	2.87

^a units of ambient concentration: $\mu\text{g}/\text{m}^3$ for PM_{2.5}, PM₁₀, nitrates, sulphates, SO₂; 6h ppb for O₃

Source: ExternE and own assumptions

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Finally, it is assumed that the government covers 80% of medical costs through the social security system.

3. SIMULATION RESULTS

In this section we assess the importance of introducing these three feedback effects in the GEM-E3 model, by comparing the standard GEM-E3 model with the extended version for two scenarios.

3.1. Scenario description

We compare the welfare effects of two environmental policy instruments that aim to reach the Kyoto target of the EU. However, while the Kyoto protocol requires a reduction of greenhouse gases by 8% compared to the 1990 level, we formulate this target in terms of CO₂ emissions in this paper. The two policy instruments are a CO₂ tax and grandfathered CO₂ emission permits. Both policies are implemented at the country level in the target period 2008-2012 with the CO₂ target for each country given by the EU burden sharing agreement.

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The revenue recycling strategy is different for the two environmental policies. For the tax scenario budget neutrality is obtained by reducing the social security contributions. In the permit scenario no specific recycling strategy is assumed for the government. As in any CGE model overall equilibrium is assured.

The reference scenario is a “business as usual scenario” in which no measures are taken to reduce CO₂ emissions. It implies therefore a relative important growth for these emissions by 2008-2012, the target period for the Kyoto protocol. Hence the Kyoto protocol requires a substantial reduction effort in that period.

3.2. Results

Table 3 and Table 4 presents the simulation results for two EU countries, Germany and Belgium. The results are similar for the other EU countries, though the relative impacts may vary.

The reduction target for Belgium is a CO₂ reduction by 7.5% w.r.t. 1990, for Germany CO₂ emissions should be reduced by 21% w.r.t. the 1990 levels⁸.

⁸ Compared to 1995 emission levels (base year in GEM-E3) this corresponds with a reduction target of 15.5% for Belgium and 15% for Germany.

The main impact of modelling the feedback of the change in the environment goes through the labour market. The improvement of the local environment by the CO₂ policy has a positive effect on public health and hence decreases the number of working hours lost because of health problems. The final impact on employment is negative compared to the result without feedback. This induces a decrease in the real wage rate w.r.t. the standard model. However, this impact on the real wage rate has a positive effect on the competitiveness of the economy, boosting the exports and improving the current account. This effect is more pronounced in Germany because the improvement of the environment is also the greatest there. It must be remembered that the countries do not only benefit from the reduction in emissions in their own country but also from that in the other countries through the transport of emissions. This effect is much greater in countries in the middle of Europe.

In order to determine the relative importance of the three types of feedback effect we have performed simulations with the GEM-E3 model in which only the feedback effect on consumption and the government budget is modelled⁹. We find that a reduction in air pollution has a positive impact on the government budget and that the production and consumption of medical services falls. However, the effects on economic welfare are negligible. The feedback effect on the production sectors is the one that drives our findings in Table 3 and Table 4.

Introducing the feedback effects influences the ranking of the CO₂ tax and the grandfathered tradable permits. In the standard model permits perform better than the CO₂ tax in terms of welfare, even though the CO₂ tax allows to reduce the social security contributions. This is because GEM-E3 takes into account the interactions with the other countries. With permits the burden of environmental policy is shifted more to the foreign sector, implying a smaller loss in income.

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The ranking of the two environmental policies is reversed when the feedback effects are considered. This is mainly explained by the labour market effect. The loss of employment is greater than in the standard model, or its increase is smaller, inducing a greater decrease in consumers' income. With the CO₂ tax the revenue recycling via the social security contributions allows to partly offset this effect.

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⁹ The results can be obtained from the authors upon request.

Table 3: Macroeconomic and environmental impact of the climate policies under alternative feedback mechanism: Germany

Country: Germany	Standard GEM-E3 model		GEM-E3 model + feedback effects	
	Domestic CO ₂ tax	Domestic grandfathered pollution permits	Domestic CO ₂ tax	Domestic grandfathered pollution permits
Macroeconomic aggregates (% change w.r.t. benchmark)				
GDP	0.0	-0.5	+2.6	+1.9
Employment	+0.4	-0.2	-0.3	-1.0
Private consumption	-0.5	-0.3	-0.3	-1.0
Investment	-0.3	-0.2	+0.6	+0.6
Energy consumption	-15.5	-15.7	-14.7	-15.4
Exports	-0.5	-2.3	+7.8	+6.7
Imports	-1.7	-1.0	-2.3	-2.3
Real wage rate	+0.2	-0.7	-0.8	-3.1
Relative consumer price	+1.4	+3.5	-3.7	-2.2
Terms of trade	0.0	+0.9	-3.6	-3.6
Public surplus (% of GDP)	0.0	-0.3	0.0	+0.2
Current account (% of GDP)	+0.2	-0.1	+1.5	+1.4
Emissions (% change w.r.t. benchmark)				
CO ₂	-22.3	-22.3	-22.8	-22.8
NO _x	-24.3	-24.1	-24.8	-24.6
SO ₂	-26.4	-24.9	-27.5	-25.5
VOC	-20.4	-20.9	-20.8	-21.5
PM	-26.7	-25.2	-27.7	-25.9
Policy				
Environmental tax revenue (% of GDP)	+1.7		+1.9	
Change of social security rate w.r.t. benchmark	-2.0		-3.0	
CO ₂ marginal abatement costs (EURO/tonne CO ₂)	48.0	50.9	57.4	59.6
Welfare (% change w.r.t. benchmark)				
Economic welfare	-0.6	-0.2	-0.1	-0.3
Environmental welfare	127.9	125.4	+128.9	126.2
Total welfare	-0.02	0.4	+0.4	+0.2

Table 4: Macroeconomic and environmental impact of the climate policies under alternative feedback mechanism: Belgium

Country: Belgium	Standard GEM-E3 model		GEM-E3 model + feedback effects	
	Domestic CO ₂ tax	Domestic grandfathered pollution permits	Domestic CO ₂ tax	Domestic grandfathered pollution permits
Macroeconomic aggregates (% change w.r.t. benchmark)				
GDP	-0.5	-1.4	+1.2	+0.5
Employment	+1.0	-0.4	+0.7	-1.0
Private consumption	-0.4	-0.7	-0.4	-1.5
Investment	-0.6	-0.3	+0.0	+0.3
Energy consumption	-25.7	-24.4	-25.4	-24.0
Exports	-3.4	-3.5	-0.2	0.0
Imports	-3.5	-2.7	-2.1	-1.6
Real wage rate	+2.1	-1.7	+1.2	-4.0
Relative consumer price	+3.1	+5.3	+1.5	+2.3
Terms of trade	+1.0	+1.0	0.0	0.0
Public surplus (% of GDP)	0.0	-0.4	0.0	+0.1
Current account (% of GDP)	+0.8	-0.1	+1.9	+1.2
Emissions (% change w.r.t. benchmark)				
CO ₂	-35.6	-35.6	-35.5	-35.5
NO _x	-38.1	-38.2	-37.9	-38.1
SO ₂	-52.5	-51.6	-52.4	-51.4
VOC	-27.1	-28.0	-27.1	-28.0
PM	-51.9	-51.2	-52.0	-51.2
Policy				
Environmental tax revenue (% of GDP)	+3.9		+4.0	
Change of social security rate w.r.t. benchmark	-7.0		-9.0	124.9
CO ₂ marginal abatement costs (EURO/tonne CO ₂)	104.5	118.9	110.6	
Welfare (% change w.r.t. benchmark)				
Economic welfare	-1.0	-0.4	-0.7	-0.8
Environmental welfare	352.1	353.6	350.8	353.1
Total welfare	-0.3	0.2	-0.2	-0.3

4. CONCLUSIONS

The paper shows that it is important to include the health related effect of air pollution on production in order to make a correct evaluation of environmental policies. The welfare effects of the two environmental policies considered here clearly change with respect to the standard GEM-E3 model that assumes that environmental quality enters as a separable term in the utility function. Moreover, the ranking between the two environmental policies is reversed.

Modelling the morbidity-related health effects on consumption and the government budget is found to have a much smaller and almost negligible impact. This has to be qualified by two remarks. We do not yet model the medical expenditures related to mortality. Nor do we consider the impact of the health effects on total time available to the consumers. Including these aspects would increase the impact on consumption. We however expect the direct impact of mortality on the production side to be small, as it mainly concerns the elderly.

Deleted: non-working population

Our findings clearly depend on these and other assumptions we made for modelling the feedback effects. First, the conclusion are dependent on the institutional setting in Europe. Secondly, the information that we used is still surrounded by uncertainty. This is the case for, for example, the transport and chemical transformation processes of pollutants, the dose-response relationships and the valuation of the health effects.

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APPENDIX A

Table A.1: Air pollution damages and the impact of air pollution on working days

	Damage (EURO95/ 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
PM₁₀	19.89			17.25
<i>Acute mortality</i>	<i>0.29</i>			
<i>Chronic mortality</i>	<i>15.39</i>			
<i>Acute morbidity</i>	<i>1.99</i>			<i>17.24</i>
Respiratory hospital admissions	0.02	0.001	20	0.03
Congestive heart failure	0.02			
Cerebro-vascular hospital admissions	0.04	0.003	20	0.07
Restricted activity days	1.50	13.20	0.75	9.90
Bronchodilator usage				
- asthmatic children	0.02			
- asthmatic adults	0.17	3.01	1	3.01
Cough				
- asthmatic children	0.03			
- asthmatic adults	0.17	3.11	1	3.11
Wheeze				
- asthmatic children	0.01			
- asthmatic adults	0.01	1.13	1	1.13
<i>Chronic morbidity</i>	<i>2.22</i>			<i>0.01</i>
Chronic bronchitis				
- adults	2.06	0.01	1	0.01
- children	0.07			
Chronic cough in children	0.09			
SO₂	0.54			0.03
<i>Acute mortality</i>	<i>0.52</i>			
<i>Acute morbidity</i>	<i>0.02</i>			<i>0.03</i>
Respiratory hospital admissions	0.02	0.001	20	0.03

Source: ExternE and own assumptions

Table A.1(continued): Air pollution damages and the impact of air pollution on working days

	Damage (EURO/ 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}	32.89			28.88
<i>Acute mortality</i>	<i>0.49</i>			
<i>Chronic mortality</i>	<i>25.48</i>			
<i>Acute morbidity</i>	<i>3.34</i>			<i>28.86</i>
Respiratory hospital admissions	0.03	0.002	20	0.05
Congestive heart failure	0.03			
Cerebro-vascular hospital admissions	0.07	0.006	20	0.11
Restricted activity days	2.52	22.18	0.75	16.63
Bronchodilator usage				
- asthmatic children	0.03			
- asthmatic adults	0.28	5.03	1	5.03
Cough				
- asthmatic children	0.06			
- asthmatic adults	0.29	5.17	1	5.17
Wheeze				
- asthmatic children	0.01			
- asthmatic adults	0.02	1.87	1	1.87
<i>Chronic morbidity</i>	<i>3.58</i>			<i>0.02</i>
Chronic bronchitis				
- adults	3.28	0.02	1	0.02
- children	0.12			
Chronic cough in children	0.18			
O₃	1.54			2.87
<i>Acute mortality</i>	<i>0.86</i>			
<i>Acute morbidity</i>	<i>0.68</i>			<i>2.87</i>
Respiratory hospital admissions	0.06	0.01	20	0.09
Minor restricted activity days	0.12	10.31	0.25	2.58
Change in asthma attacks	0.01	0.20	1	0.20
Symptom days	0.50	43.56	0	0.00

Source: ExternE and own assumptions