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National Economic Impacts of an EU Environmental Policy - An Applied General Equilibrium Analysis

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Abstract

The objective of this paper is to quantify the economic effects of the introduction of a system of tradable permits in the European Union (EU). For this purpose we use linked applied general equilibrium models (AGE) for eleven EU member countries. This method enables us to measure the change in competitiveness for domestic industries, the impact on growth, employment and inflation in member countries, and the cost and benefits of a cooperative approach to adhere to a EU target of emissions of air pollutants. The results we will present are first results from the SOLVGE/GEM-E3 Projekt. GEM-E3 stands for General Equilibrium Modeling for Energy - Economy - Environment, a joint undertaking of NTUA-Athens (P. Capros, P. Georgakopoulos), CES-KULeuven (S. Proost and D. Van Regemorter), Univ. Mannheim and ZEW (K. Conrad and T. Schmidt), GEMME-CEA (N. Ladoux), Univ. Strathclyde (P. MacGregor), CORE-UCL (Y. Smeers), .

With respect to a policy on greenhouse gases we will quantify the economic impact for the EU by introducing a EU-wide tradable permit system, free of charge and based on the present energy intensity and energy mix. Under growth there will be a positive market price for permits with demand by countries where the cost of substitution are high and supply by those countries where the cost of substitution are low. We will measure economic performance and trade flows under a noncoordinated CO_2 policy where each country limits the emission of CO_2 by 10% and will compare the result with a cooperative outcome where the European Union as a decision maker aims at reducing CO_2 by 10%.

1. Introduction

Preventive measures to protect the earth's atmosphere and the associated policies required are at the centre of international conventions concerning the environment. A large number of states have decided or are beginning to decide in favour of a drastic reduction of energy-related carbon dioxide (CO_2) and sulfur dioxide (SO_2) emissions. The greenhouse gas CO_2 results from the combustion of fossil carbon, so that a reduction of CO_2 emissions can only be achieved by reducing the use of fossil energy carriers. These sources of energy, however, are the backbone of current energy supply. Since a reduction of CO_2, SO_2 or NO_X emissions cannot be achieved by technical measures alone, the use of economic instruments such as taxes and marketable permits was also, and still is, taken into consideration to achieve predefined emission goals. The objective of this paper is to quantify the economic effects of the introduction of tradable permits for CO_2 in the European Union (EU). For this purpose we use linked applied general equilibrium models (AGE) for eleven EU member countries. This method enables us to measure the change in competitiveness for domestic industries, the impact on growth, employment and inflation in member countries, the cost effectiveness of a coordinated environmental policy and the costs and benefits of a cooperative approach to adhere to a EU target of emissions of air pollutants. The results we will present are first results from the SOLVEGE/GEM-E3 Project. GEM-E3 stands for General Equilibrium Modelling for Energy - Economy - Environment, a joint undertaking of NTUA-Athens (P. Capros, P. Georgakopoulos), CES-KULeuven (S. Proost and D. Van Regemorter), Univ. Mannheim and ZEW (K. Conrad and T. Schmidt), GEMME-CEA (N. Ladoux), Univ. Strathclyde (P. MacGregor), CORE-UCL (Y. Smeers). The data consist of national social accounting matrices, an extension of the social account by an input-output table and of an environmental data base.

The specification of the present minimum standard model consists of unit cost functions of the nested CES type for eleven industries. There are overall CES functions in the KLEM (capital, labor, energy, and material) input prices with price diminishing (factor augmenting) technical change and CES sub-cost functions. The foreign trade specification is of the Armington type. The demands for the goods are distinguished not only by types of goods (eleven) but also by place of production (eleven EU member countries and the rest of the world). The share parameters in the CES specification for a good i supplied by each of the twelve countries and demanded in a country k will be calculated using a trade matrix for each of the eleven goods.

The model of consumer behavior in each social group is based on an extended linear expenditure system. The consumers choose the optimal allocation of expenditure for nondurables and for services of durables across 12 consumption categories and saving. Consumption matrices are used to break down these categories into their origins (11 goods). The prices of the services from durables are expressed in cost prices consisting of user costs and all cost components linked to the use of the durables (e.g. a gasoline tax, a motor vehicle tax). The interest rate takes care of the closure rule. Trade in goods and services between countries will not be balanced by endogeneous exchange rates but the model will present changes in the national balances of trade.

Two environmental problems will be considered: global warming and acidification. Abatement cost functions of the main acidification components, i.e. SO_2 and NO_x have been estimated for several industries. These functions depend on the degree of abatement (set as a standard by regulation or determined by the firm as an endogeneous variable) and they will increase the price or unit cost of using emission intensive inputs. Yearly increases in real net investment in equipment for cleaner air by industry and country will be used to calculate degrees of abatements in the base year. Finally, from total deposition (emissions of SO_2 and NO_x) at a receptor due to a specific source we derive (i) deposition at a receptor per unit emission from a source country (transport coefficient) and (ii) the background depositions in every country.

With respect to a policy concerning the problem of greenhouse gases we will quantify the economic impact for the EU by introducing a EU-wide tradable permit system, free of charge and based on the present energy intensity and energy mix. If we then depreciate tradable permits by 10 percent, there will be a positive market price for permits with demand by countries where the cost of substitution are high and supply by those countries where the cost of substitution are low. We will look into the implications of reducing CO_2 by 10% nation by nation via a permit system versus a EU-wide reduction of 10%. Of interest is who will gain and who will loose under a cooperative approach.

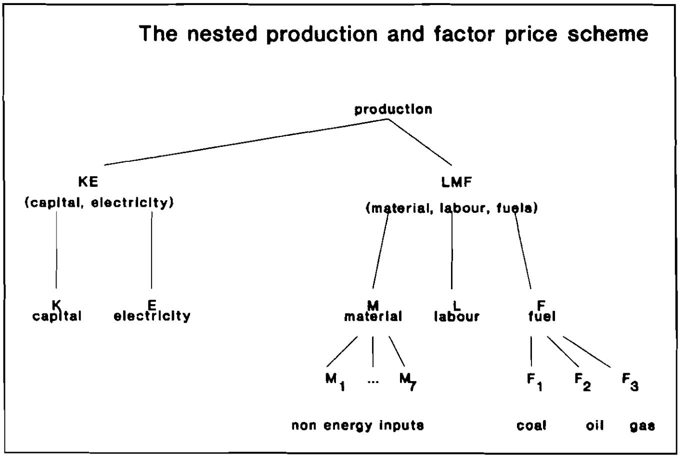
Despite the desirable pioneer role as a signal for action being required, we expect higher prices and a loss in growth under an unilateral action taken by one country. However, if the EU decided to introduce an emission tax or a system of tradable permits, losses in growth might be kept, as we will investigate in this paper, within acceptable limits.

2. The Specification of the Standard Version of the GEM-E3 Model

2.1 Cost function and input coefficients for the KLEM aggregate

We characterize the technology of a cost minimizing industry by nested CES cost functions. $C(X, \overline{PKE}, \overline{PLMF})$ is the cost function at the first stage with input prices for the capital/electricity aggregate KE and the labor/material/fuel aggregate LMF. Our production function is assumed to be CES in KE and LMF with factor-augmenting technical change. Hence there is price diminishing technical progress in the cost function in terms of effective input prices. Figure 1 shows the nested production structure.

Figure 1



Profit maximization under constant returns to scale implies revenue PX · X equal to cost which explains the output price PX of domestic production in terms of a CES unit cost function:

$$(1) \qquad PX = \left[d_1 \cdot \overline{PKE}^{1-\sigma_x} + d_2 \cdot \overline{PLMF}^{1-\sigma_x}\right]^{\frac{1}{1-\sigma_x}}$$

where $\overline{PKE} = PKE \,/\, g_{KE}(t)$ *with* $g_{KE}(t) = exp\,(\bar{g}_{KE} \cdot t)$ as price diminishing technical progress. Similar for the input aggregate LMF, i.e. for g_{LMF} (t) ($d_1^{\sigma_x}$ gives the distribution parameter in the primal production function). From

Shephard's Lemma we derive the factor demand functions as variable input coefficients:

$$(2) \qquad \frac{KE}{X} = d_1 \cdot \left(\frac{PX}{PKE}\right)^{\sigma_x} \cdot g_{KE}(t)^{\sigma_x - 1}$$

$$(3) \qquad \frac{LMF}{X} = d_2 \cdot \left(\frac{PX}{PLMF}\right) \cdot g_{LMF}(t)^{\sigma_x - 1}$$

In principle, one could include all the input prices of the model in one CES unit cost function. This, however, would imply the assumption, that the elasticity of substitution between all inputs is the same. We therefore specify sub-cost functions for the capital/electricity aggregate and for the LMF-aggregate with different elasticities of substitution. The price function for the KE aggregate at that second level is:

$$(4) \qquad PKE = \left[d_{1K}\, \overline{PK}^{1-\sigma_{KE}} + d_{1E}\, \overline{PE}^{1-\sigma_{KE}}\right]^{\frac{1}{1-\sigma_{KE}}}$$

with $\overline{PE} = PE \,/\, g_E\,(t)$, expressing electrictiy augmenting (price diminishing) technical progress. The price-dependent composition of the capital/electricity aggregate is:

$$(5) \qquad \frac{K}{KE} = d_{1K} \cdot \left(\frac{PKE}{PK}\right)^{\sigma_{KE}} \cdot g_K(t)^{\sigma_{KE} - 1}$$

and

$$(6) \qquad \frac{E}{KE} = d_{1E} \cdot \left(\frac{PKE}{PE}\right)^{\sigma_{KE}} \cdot g_E\,(t)^{\sigma_{KE} - 1}$$

In order to determine the capital input coefficient, one has to multiply (5) by (2):

$$(7) \qquad a_K = \frac{K}{X} = \frac{K}{KE}\,(\cdot) \cdot \frac{KE}{X}\,(\cdot)$$

Capital input as derived from (7) is the desired capital stock, say K_{des} (if stocks are proportional to service flows). In the standard version of the GEM-E3 model we treat, however, capital as a quasi-fix stock over the current year at a level from the end of the previous year, say K_{-1}. We therefore use (7) to determine an endogeneous ex-post price of capital based on a rate of return which the industry has earned ex-post. For that purpose we solve (7) for PK_{post}:

$$PK_{post} = f\,(X,\ K_{-1},\ PX,\ \overline{PE},\ g_K(t),\ g_{KE}(t))$$

PK_{post} is the endogeneous shadow price of capital which clears the market for fixed K_{-1}. It will be used to calculate capital income $PK_{post} \cdot K_{-1}$ in period t. It is easy to check that our calculation of PK_{post} is equivalent to calculating it from the zero profit condition[1].

If we determine an exogeneous ex ante price of capital PK_{ante}, then (7) can be employed to determine the desired stock of capital K_{des}. Let this ex ante price be the standard user cost of capital formula:

$$PK_{ante} = PI(r + \delta)$$

where PI is the price of investment goods, r is the rate of return on risk-free government bonds (exogeneous or determined by the closure rule) and δ is the rate of replacement. Then the desired capital stock is

$$\textbf{(8)} \qquad K_{des} = X \cdot d_{1K} \cdot \left(\frac{PKE}{PK_{ante}}\right)^{\sigma_{KE}} \cdot g_K(t)^{\sigma_{KE}-1}\ d_1 \cdot \left(\frac{PX}{PKE}\right)^{\sigma_x} g_{KE}(t)^{\sigma_x-1}$$

with PK_{ante} appearing also in PKE as specified under (4).
Net investment I_{net} with "adjustment" is

$$\textbf{(9)} \qquad I_{net} = m(K_{des} - K_{-1})$$

Finally, capital stock for the next period is

$$\textbf{(10)} \qquad K = I_{br} + (1 - \delta)K_{-1}$$

where $I_{br} = I_{net} + \delta \cdot K_{-1}$.
We should finally concede that a specification of a restricted cost function C (X, K_{-1}, PKE, PLMF) would have been the appropriate approach to a model with a quasi-fixed capital stock. In such a case, however, the system of prices would depend also on X which complicates the solution process for the linked models.

If capital is mainly machinery and electrical equipment, then capital and

[1] Insert into the zero profit condition (with K_{-1} for K) the inputs E, and LMF from (3) and (6) and solve for PK by using (1).

electricity are used in fixed proportions. An alternative approach then would be to define the price of capital in terms of a cost price (Conrad (1983)). A higher price of electricity increases the cost of using capital, which, in turn, may increase the demand for labor. In order to model such a relation we introduce a partial linkage of capital and electricity. In the cost function

$$C(KE, PK, PE) = \min_{K,E} \; (PK \cdot K + PE \cdot E) \; s.t. \; KE = f(K, E)$$

we partition E by $E = \alpha_E \cdot K + \tilde{E}$ where $\alpha_E \cdot K$ is the electricity demand derived from K and $\tilde{E}$ is the flexible electricity which can be conservated if substituted by other inputs. Inserting E in the cost definition yields:

$$C(KE, PK, PE) = \min_{K,\tilde{E}} \; (PK \cdot K + PE(\alpha_E \cdot K + \tilde{E}) \; s.t. \; KE = f(K, \alpha_E \cdot K + \tilde{E})$$

or

$$C(KE, \tilde{PK}, PE) = \min_{K,\tilde{E}} \; ((PK + \alpha_E \, PE) \, K + PE \cdot \tilde{E} \quad s.t. \; KE = F(K, \tilde{E}))$$

where $\tilde{PK} = PK + \alpha_E \, PE$ is the cost price of capital. Cost prices reflect the aspect of linked inputs and provide for a different pattern of substitution. The demand for capital K and flexible energy $\tilde{E}$ can be derived by Shephard's Lemma.

We next have to specify a price function for the aggregate LMF:

$$PLMF = \left[d_{2L} \, \overline{PL}^{1-\sigma_L} + d_{2M} \, \overline{PM}^{1-\sigma_L} + d_{2F} \, \overline{PF}^{1-\sigma_L} \right]^{\frac{1}{1-\sigma_L}}$$

The price-dependent composition of this aggregate follows again from Shephard's Lemma:

$$\frac{input \; i}{LMF} = d_{2i} \left(\frac{PLMF}{P \, i} \right)^{\sigma_L} g_i(t)^{\sigma_L - 1}, \qquad i = L, M, F.$$

We finally have a unit cost function on the third level for the price of fuel (coal, gas, oil)

$$PF = \left[\sum_{i=1}^{m} \delta_{1,i} \cdot \overline{PY}_i^{1-\sigma_F} \right]^{\frac{1}{1-\sigma_F}}$$

with $\bar{PY}_i = \frac{PY_i}{g_{F_i}(t)}$, expressing energy augmenting (price diminishing) technical progress.

The price-dependent composition of the fuel aggregate is

$$(11) \qquad \frac{F_i}{F} = \delta_{1,i} \left(\frac{PE}{PY_i}\right)^{\sigma_F} g_{F_i}(t)^{\sigma_F - 1} \qquad i = 1,\dots,m.$$

Similarly, we choose a CES specification for the unit cost function for material:

$$PM = \left[\sum_{i=m+1}^{n} \delta_{2,i} \bar{PY}_i^{1-\sigma_M}\right]^{\frac{1}{1-\sigma_M}}$$

with $\bar{PY}_i = \frac{PY_i}{g_{M_i}(t)}, \qquad i = m+1,\dots,n$

The cost-minimizing allocation of material to its components follows from:

$$(12) \qquad \frac{M_i}{M} = \delta_{2,i} \left(\frac{PM}{PY_i}\right)^{\sigma_M} \cdot g_{M_i}(t)^{\sigma_M - 1}$$

If we multiply the overall input coefficient by the sub-input coefficient we obtain the input coefficients a_i:

$$(13) \qquad a_i = \frac{F_i}{X} = \frac{F_i}{F}(\cdot) \cdot \frac{F}{LMF}(\cdot) \cdot \frac{LMF}{X}(\cdot), \qquad i = 1,\dots,m$$

$$(14) \qquad a_i = \frac{M_i}{X} = \frac{M_i}{M}(\cdot) \cdot \frac{M}{LMF}(\cdot) \cdot \frac{LMF}{X}(\cdot), \qquad i = m+1,\dots,n \text{ and}$$

$$a_L = \frac{L}{X} = \frac{L}{LMF}(\cdot) \cdot \frac{LMF}{X}(\cdot).$$

The $(\cdot)$ indicates that the coefficients depend on relative prices.

2.2 The foreign trade specification

For modeling intra-industry foreign trade between the EU member countries, the Armington approach is widely accepted: domestically produced goods and imports from different countries are imperfect substitutes. Thus dual to a CES production function $Y_c = f(X_c, IM_c)$, giving supply Y_c in country c as an aggregate of domestic production X_c and imports IM_c, is a CES unit cost function

$$(15) \qquad PY_c = \left[cx \cdot PX_c^{1-\sigma_x} + (1 - cx)\ PIM_c^{1-\sigma_x}\right]^{\frac{1}{1-\sigma_x}}$$

where PY_c, PX_c, and PIM_c are the corresponding prices of Y_c, X_c, and IM_c (price of aggregated imports is in national currency of country c). From this cost function we derive the share of domestic production in total supply:

$$(16) \qquad \frac{X_c}{Y_c} = cx \cdot \left(\frac{PY_c}{PX_c}\right)^{\sigma_x}$$

and the share of aggregate import in total supply:

$$(17) \qquad \frac{IM_c}{Y_c} = (1 - cx) \cdot \left(\frac{PY_c}{PIM_c}\right)^{\sigma_x} .$$

If the model determines total supply, then we have to allocate aggregate import demand, derived from (17), to the 11 EU member state countries and to the rest of the world who contribute to this aggregate import demand. Thus import consists, in other words, of the exports of the 12 countries in that good. Therefore, in the GEM-E3 model the demands for the 11 goods are also distinguished by place of production. There will be French import demand of consumer goods produced in the United Kingdom and produced in Spain. To obtain such a trade matrix with 11 x 12 import demand functions by good and place of production we specify a CES import unit cost or price function:

$$(18) \qquad PIM_c = \left[\sum_{k=1}^{12} cm_k \left(\frac{PIM_k}{e_{k,c}}\right)^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}} \qquad c = 1, \dots, 11$$

where PIM_k is the price of imports as the export price by country k. As there are import taxes and duties (t_{dut}), it is $PIM_k = (1 + t_{dut}) \cdot PY_k$ (Since we distinguish by 11 goods, we have to write $PIM_{i,k} = (1 + t_{i,dut}) \cdot PY_{i,k}$ for a good i and a country k). $e_{k,c}$ is the exchange rate index in currency of country k per unit currency of country c. Given the price index PIM_{ROW} and the exchange rates $e_{ROW,c}$, the eleven prices PIM_c can be calculated. This permits us to determine next from (15) PY for a certain good and then the shares in (16) and (17).

Again, a cost minimizing composition of the import aggregate is the objective of the importing country. Shephard's Lemma, applied to the cost function PIM_c in (18), yields this composition:

(19) $$\frac{IM_{k,c}}{IM_c} = cm_k \left(\frac{PIM_c}{PIM_k \;/\; e_{k,c}} \right)^{\sigma_m} , \qquad k = 1,\ldots,12$$

where $IM_{k,c}$ is the import by country c from country k in currency of country c. Because of $\sum_k cm_k = 1$, the adding up condition $\sum_k (PIM_k \;/\; e_{k,c}) \cdot IM_{k,c} = PIM_c \cdot IM_c$ is automatically satisfied. If we multiply (19) by IM_c, derived from equation (17), we can fill a trade flow matrix for each of our 11 commodities. Such a trade matrix looks as follows:

country	1	. . .	c	. . .	12	export
1	$\left(\frac{PIM_1}{e_{1,1}}\right) \cdot IM_{1,1}$		. . .		$\left(\frac{PIM_1}{e_{1,12}}\right) \cdot IM_{1,12}$	EX_1
. . .						. . .
k	. . .		$\left(\frac{PIM_k}{e_{k,c}}\right) \cdot IM_{k,c}$		. . .	EX_k
. . .						. . .
12	$\left(\frac{PIM_{12}}{e_{12,1}}\right) \cdot IM_{12,1}$		. . .		$\left(\frac{PIM_{12}}{e_{12,12}}\right) \cdot IM_{12,12}$	EX_{12}
import	$PIM_1 \cdot IM_1$	. . .	$PIM_c \cdot IM_c$	. . .	$PIM_{12} \cdot IM_{12}$	see (20)

The column sums yield the value of import of country c in currency of country c. The quantity elements in row k, $IM_{k,c}$ (c = 1,...,12), are in currency of country c. Multiplied by the exchange rate $e_{k,c}$ in currency of country k per unit of currency of country c, they can be sumed up to yield export EX_k of country k, i.e.

(20) $$EX_k = \sum_c e_{k,c} \cdot IM_{k,c}$$

EX_k in turn enters final demand in the input-output accounting system. The trade surplus (TS) (deficit if negative) for a good is:

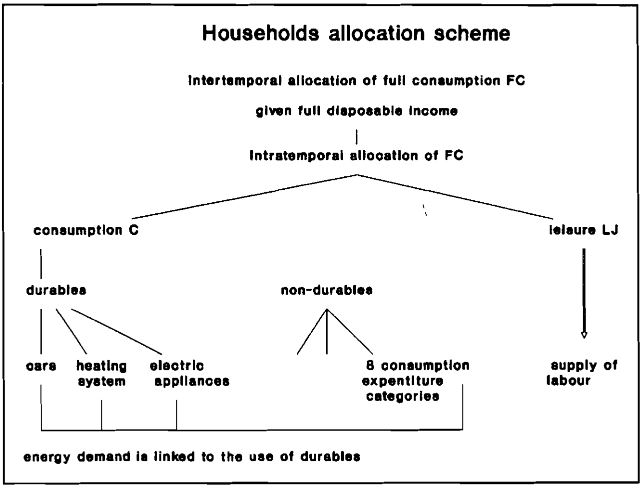
$$TS_k = PY_k \cdot EX_k - PIM_k \cdot IM_k$$

In the Standard Version of the GEM-E3 model the exchange rates are exogeneous and the balances of trade are calculated as residuals.

2.3 Consumer demand and labor supply

Usually the behavior of consumers is assumed to perform a two-stage budgeting procedure: an intertemporal allocation of lifetime wealth endowment between present and future consumption of goods and leisure, and an intratemporal allocation of consumption into categories. The latter are then transformed into consumption by product. Figure 2 shows the household's allocation problem.

Figure 2



Furthermore, if the distributional impacts of policies are to be assessed, a disaggregation into several types of households is required. In the standard GEM-E3 version we consider a representative consumer who is characterized by an expenditure function for "full" expenditure which consists of expenditures for non-durable goods and for leisure given the stocks of consumer durables. Since environmental regulation affects the use and purchase of consumer durables such as cars, electric appliances, and heating, a model of consumer behavior should integrate demand for durables and for non-durables. Demand for non-durables like gasoline or electricity and demand for services from durables has to be reconciled with investment demand for modifying the stocks of durables towards their optimal levels. We therefore employ a restricted expenditure function with stocks of durables as quasi-fixed goods. The expenditure function is derived from the Stone-Geary utility function which underlies the linear expenditure system.

At the first stage the household determines an allocation of his resources between present and future consumption by maximizing an intertemporal utility function subject to an intertemporal budget constraint:

$$\max_{C_t, LJ_t} \Sigma_t \, (1 + s)^{-t} \, (\beta_c \ln(C_t - CO) + \beta_{LJ} \ln(LJ_t - LJO))$$

s.t.

$$WT = \Sigma_t \, (1 + r)^{-t} \, (PC_t \cdot C_t + PLJ_t \cdot LJ_t)$$

where WT is total wealth. C_t is real private consumption, CO its subsistence level, LJ_t is leisure and LJO its subsistence level, s is the subjective discount rate and r is the nominal interest rate. An initial commitment for leisure could be LJO = 12 hrs/day · average working days per year. The price of leisure is PLJ = $(1 - t_m) \cdot$ PL where t_m is the marginal tax rate for labor income. Under some assumptions (e.g. a constant expected rate of inflation) the following demand functions for consumption and leisure can be derived:

$$(21) \qquad C = CO + \frac{s}{r_r} \, \frac{\beta_C}{\beta_C + \beta_{LJ}} \, \frac{1}{PC} \, (Y_{disp} + PLJ \cdot LJ - PC \cdot CO - PLJ \cdot LJO)$$

$$(22)\quad LJ = LJO + \frac{s}{r_r} \frac{\beta_{LJ}}{\beta_C + \beta_{LJ}} \frac{1}{PLJ} (Y_{disp} + PLJ \cdot LJ - PC \cdot CO - PLJ \cdot LJO)$$

The last equation is implicit in LJ and has to be solved for LJ. Leisure and labor demand then add up to the yearly time endowment. The savings of housholds can then be determined by
$S = Y_{disp} - PC \cdot C$.

Next we subtract from consumption expenditure the demand for durables and the demand of energy associated with using the durables. This gives expenditure e for non-durables. These expenditures will be allocated on the second stage of the consumer decision problem:

$$(23)\quad e = \sum_{i=1}^{n} p_i \, C_i$$

The expenditure function with three quasi-fixed durable goods (Z_1, Z_2, Z_3 for cars, electric appliances, and heating, respectively) is:

$$(24)\quad e(p_1, \ldots, p_n; u; Z_1, Z_2, Z_3) = \sum_{i=1}^{n} p_i \cdot C_{o,i} + u \cdot \prod_{j=1}^{3} (Z_j - Z_{o,j})^{-\gamma_j} \cdot \prod_{i=1}^{n} \left(\frac{p_i}{\beta_i} \right)^{\beta_i}$$

where $p_i = PY_i\,(1 + t_i)$ is the market price for the good, u is the utility level, $C_{o,i}$ is the minimum required quantity of good i, $Z_{o,j}$ is the minimum required quantity of a durable good j, and $\sum p_i \cdot C_{o,i}$ is "subsistence expenditure". The expenditure minimizing demand for non durable goods, given utility u and the stocks of the three durables, can be derived by partial differentiation of the expenditure function with respect to the prices:

$$(25)\quad C_i = C_{o,i} + \frac{\beta_i}{p_i} \left(e(\cdot) - \sum_{i=1}^{n} p_i \cdot C_{o,i} \right), \qquad i = 1, \ldots, n$$

Desired stocks of durables and ex-post service prices of durables can be derived in an analogous way as used for the restricted cost function approach. With an exogeneous ex-ante user cost of durables p_{Z_j}, the desired stock follows from

$$\frac{\partial\, e\,(\cdot\,,\hat{Z}_j)}{\partial Z_j} = - p_{Z_j}, \qquad i.e.$$

(26) $$\hat{Z}_j = Z_{oj} + \frac{\gamma_j}{p_{Z_j}} \left(e(\cdot) - \sum_{i=1}^{n} p_i \cdot C_{o,i} \right)$$

Purchases of new durables under adjustment restrictions ($0 < m \leq 1$) are:

$$I_{Z_j}^{net} = m_j (\hat{Z}_j - Z_{-1,j}) \qquad j = 1, 2, 3.$$

We finally obtain consumer expenditures $PC \cdot C$ on durables and on the services of non-durables from (27):

(27) $$PC \cdot C = \sum_{i=1}^{n} p_i\, C_i + \sum_{j=1}^{3} p_{Z_j} (Z_{-1,j} + I_{Z_j}^{net})$$

We should finally say some words to the specification of the user cost of a durable, p_{Z_j}. In principle, we could set p_Z equal to PI $(r + \delta)$ where PI is the price of the durable, δ is the rate of replacement and r is the interest rate. However, as some non-durable goods as gasoline, electricity, and heating are linked to the stock of durables, we used a composition of these goods into a linked part and into a disposable part. The idea behind such a composition is that demand for gasoline (C_G) is linked to the use of the stock of automobiles (Z). Or, in algebraic terms, $C_G = \alpha_{G,Z} \cdot Z + \tilde{C}_G$ where $\alpha_{G,Z}$ is yearly gasoline consumption per unit of purchase price of the car and $\tilde{C}_G$ is gasoline consumption from fast driving or bad maintenance of the car[2]. This implies a cost price p_z of the services of an automobile which is the user cost of capital PI $(r + \delta)$ plus the cost of gasoline, i.e. $\tilde{p}_Z = PI(r + \delta) + \alpha_{G,Z} \cdot p_G$. The introduction of a tax on CO_2 or NO_x will therefore increase the price of gasoline, hence the cost price of a car, and demand for new cars will decline. Under a carbon dioxide tax, for instance, the cost price of a car is $p_Z = PI\,(r + \delta) + \alpha_{G,z}\,(p_G + t_{CO_2} \cdot e_{CO_2})$ where t_{CO_2} is the tax rate and e_{CO_2} is the emission coefficient for gasoline. If we incorporate furthermore a property tax or motor vehicle tax rate τ, then the user cost of a car is

(28) $$p_Z = PI\,(r\,(1 + \tau) + \delta + \tau) + \alpha_{G,Z} \cdot p_G$$

For guess-estimation of the parameters $C_{o,i}$, β_i and γ_j we make use of the proper-

[2] For more detail see Conrad and Schröder (1991 b).

ties of a linear expenditure system, i.e. from guess-estimates of n income elasticities one obtains the n parameters β_i and from guess-estimates of n direct price elasticities one obtains the n parameters $C_{o,i}$, given the β_i's (and similarly for the parameters of the durables).

2.4 Demand, supply and the closure rule

The standard system of equations for an input-output model is

$$(29) \qquad Y_i = \sum_{j=1}^{n} a_{i,j} \cdot X_j + F_i$$

where F_i is final demand with $F_i = C_i + CG_i + I_i + IG_i + EX_i$. C_i is private consumption of good i, CG_i and IG_i are government consumption or investment, respectively (exogeneous), and I_i is gross investment by origin.

Since our demand system determines consumption goods by categories and our system of investment functions investment demand by destination, we require transition matrices transforming demand into deliveries from the industries. Therefore, the C_i's in final demand have to be seen as the result of the transition matrix of the type (branches x categories) multiplied by the consumption categories. Similarly, an investment matrix with fixed technical coefficients serves to compute investment demand by origin (products) from investment demand by destination (branches) as evaluated from investment behavior in (7), together with investment for replacement and decay, i.e. $\delta \cdot K_{-1}$. The system (21) can be written as a system in the unknown variables Y_i if we rewrite it as

$$(30) \qquad Y_i = \sum_{j=1}^{n} a_{ij} \cdot \left(\frac{X_j}{Y_j} \right) \cdot Y_j + F_1$$

with X_j / Y_j determined by (16).

In value terms, demand has to be equal to supply:

$$(31) \qquad PZ_i \cdot Y_i = \sum_{j=1}^{n} PY_j \cdot X_{ij} + (1 + t_i) \cdot PY_i \cdot (F_i - EX_i) + PY_i \cdot EX_i$$

where PZ_i is the market price including indirect taxes and t_i is the indirect tax rate on final demand. The accounting identity from the input side is:

$$(32) \quad PY_j \cdot Y_j = \sum_{i=1}^{n} PY_i \cdot X_{ij} + PL_j \cdot L_j + PK_j \cdot K_{-1j} + PIM_j \cdot IM_j$$

If we sum (31) over i and (32) over j and then substract (32) from (31) we obtain the national accounting identity saying that the private gross domestic production from both the flow of cost approach and from the flow of product approach should be equal, i.e.

$$(33) \quad \Sigma_j \, (PL_j \cdot L_j + PK_j \cdot K_{-1j}) = \Sigma \, PY_i \cdot F_i - \sum_j PIM_j \cdot IM_j$$

However, as we have determined already all variables in this accounting identity (endogenously or exogenously (government expenditure and K_{-1}), there is no reason why this identity should have been satisfied.

We use the rate of return r, which influences the user cost of capital $PK_{ante} = PI(r + \delta)$, as our closure variable. The left hand side of (33) is increasing in r because of higher cost of capital. The right hand side of (33) is decreasing in r because investment as a component of final demand F is falling in r (see (9)). Hence we expect an interest rate which closes the model.

3. The environmental module in GEM-E3

The scope of the environmental issue is limited to three pollutants: nitroo-xides (NO_X), sulfur dioxide (SO_2) and carbon dioxide (CO_2). For SO_2 and NO_X we specify abatement costs which will increase the cost price of using pollution intensive inputs. To derive such a cost price, we start with the primal production function approach where material input M consists of material input M_1 for production and of material input, M_2 required for complying with environmental regulation, i.e. $M = M_1 + M_2$. Let us assume that the environmentally related input M_2 is proportional to the flow of pollutants, which in turn depends on the input of fossil fuel E, i.e. $M_2 = \alpha \cdot e \cdot E$, where e is an emission or waste coefficient in terms of tons of an air pollutant per unit of the energy input. The parameter $\alpha > 0$ we assume to be constant for the moment; i.e. it does not depend on the intensity of regulation. Combining the two equations yields: $M = M_1 + \alpha \cdot e \cdot E$. Using this composition we will rewrite the standard cost minimization approach which is:

$$C(X, PK, PL, PE, PM) = \min_{K,L,E,M} \{PK \cdot K + PL \cdot L + PM \cdot M + PE \cdot E \quad s.t.\, X = f(K, L, E, M)\}.$$

We replace M by $M_1 + \alpha \cdot e \cdot E$ and obtain

$$C(X, PK, PL, \tilde{PE}, PM) = \min_{K,L,E,M} \{PK \cdot K + PL \cdot L + PM \cdot M_1 + \tilde{PE} \cdot E \quad s.t.\, X = f(K, L, E, M_1 + \alpha E)\}$$

where $\tilde{PE} = PE + PM \cdot \alpha \cdot e$ is the cost price of energy. It consists of the energy price and the additional costs due to environmental regulation when using one unit of energy input. As the cost of regulation increases with the enforcement intensity, α should not be a constant but should depend on the degree of abatement. We therefore specify α as a function in the degree of abatement a, which represents the enforcement in pollution control:

$$\alpha = c(a) \cdot a$$

The degree of abatement is defined as the ratio of abated emission over potential emissions ($0 \leq a \leq 1$) and c(a) are the costs of abatement measures per unit of emission or waste, measured in base year prices. They depend on the degree of abatement with $c'(a) > 0$ and $c''(a) > 0$. Finally, e is an emission or waste coefficient in terms of tons of an air pollutant per unit of energy input. With this interpretation of α we obtain the following cost price for energy

(34) $\tilde{PE} = PE + PM \cdot \alpha \cdot e = PE + PM \cdot c(a) \cdot a \cdot e.$

This cost price of energy increases over-proportional with an enforcement in environmental regulation. On the production side this implies an increasing share of complementary material inputs. The change of the cost price of energy will also cause the firm to alter its input choices. A stricter environmental policy will have a substitution effect which will result in a reduced demand for energy and its price complements and in an increased use of its substitutes. This integration of abatement costs in a cost-price concept will be used for modeling the impact of regulation on household and firm behavior; for the latter each sector will be treated separately.

The cost price approach can be extended for the case of several pollutants.

Then $\tilde{PE}$ is

$$(35) \quad \tilde{PE} = PE + PM\,(c_{SO}\,(a_{SO}) \cdot a_{SO} \cdot e_{SO} + c_{NO}\,(a_{NO}) \cdot a_{NO} \cdot e_{NO})$$

with abatement costs for SO_2 and for NO_X.
If there is a tax on a pollutant, then there is also a cost price component for the actual emissions, i.e.

$$(36) \quad \tilde{PE} = PE + PM \cdot c\,(a) \cdot a \cdot e + t\,(1 - a) \cdot e\ .$$

Finally, if there is an energy tax (t_E) and / or an emission tax on carbon dioxide, t_{CO}, where no convenient end-of-pipe measures exist, then the cost price is

$$(37) \quad \tilde{PE} = PE\,(1 + t_E) + t_{CO} \cdot e_{CO}\ .$$

Our approach permits to model the effect of alternative environmental policies. If there is a regulated degree of abatement, then users of furnaces have to adhere to limits of emissions which can be interpreted in terms of our model as a minimum degree of abatement $\bar{a}$. Then the degree of abatement is given and abatement costs increase the price of energy. If a tax on emission is introduced, the degree a is a decision variable of the firm. Its problem is

$$\min_a C\,(X,\ PK,\ PL,\ \tilde{PE},\ PM)\ .$$

The first order condition is

$$\left(\frac{\partial C}{\partial \tilde{PE}}\right)\left(\frac{\partial \tilde{PE}}{\partial a}\right) = 0$$

with $\tilde{PE}$ as specified in (37). Differentiating (37) with respect to a yields the cost minimizing degree of abatement

$$(38) \quad PM\,(c'\,(a) \cdot a + c\,(a)) - t = 0$$

i.e. marginal cost of abatement is equal to the tax rate.

Furthermore, future environmental regulations can be accounted for by modifying the emission coefficients for appropriate sectors. For instance, as new cars are equipped with catalytic converters, the emission of NO_X for a given amount of gasoline will fall gradually in the 1990's.

The cost price approach can be embeded in the CES price function by replacing in PE in (9) the prices of the energy components by their $\tilde{PE}_i$'s. This also increases the overall price index of energy, $\tilde{PE}$. Environmental regulation will then have an impact on the composition of the energy aggregate E according to (10). It will also increase the price of the product according to (1), and it will reduce the demand for energy according to (4). When an environmental tax is imposed it is paid to the government by the branch causing the pollution. This has the following implications for modeling the energy price:

- the price of energy, inclusive abatement cost and taxes, affects firm's decision on the input structure (at the energy level and implicitly at the aggregate KLEM level); it re-presents the user's cost of energy.
- the price of energy, exclusive taxes and abatement cost, is used to value the deliveries of the energy sectors to the other sectors.

In the modeling of the abatement activities, investment in abatement has been considered as an input for the firms and not as an investment. It is however a component of final demand which increases GDP. The costs of each branch for all pollutants i,

$$(39) \qquad PM \left(\sum_i c_i \, (a_i) \cdot a_i \cdot e_i \cdot E_i \right)$$

have to be transformed to deliveries of goods from end-of-pipe technology producing industries (through fixed coefficients). Then total delivery for abatement by demand and supply sector is added to intermediate demand X_{ij}. This procedure increases the value of intermediate inputs. To satisfy the accounting identity of the value of inputs and of the output, we have used the ex-post price of capital as a residual. Hence the cost of abatement reduces the ex-post return of capital.

The cost of using the environment as an input is incorporated into the model of consumer behavior in a similar way as done for the modeling of firm's behavior. One difference is the payment of environmental taxes to the government. In case of firms, the environmental tax is paid by the branch causing the pollution. For the household, the tax is paid by the branch delivering the pollution intensive product to the household. That is, the environmental tax is treated like the other indirect taxes paid by households. If a household purchases electricity, it pays the price of delivery which includes the costs, electricity producers accrue from using coal which causes abatement costs and an emission tax. In this case the price corresponds to the user cost of electricity. If a household purchases heating oil, its price includes only some abatement costs and emission taxes paid by the oil companies. This price becomes a user's cost price for the consumer allocation decision, if there are emission regulation for the heating system or a CO_2 tax.

We still have to solve the problem of how to measure the degree a of abatement. A measure of regulation could be pollution abatement expenditures, compliance status, enforcement activity or emissions. We measure regulation by calculating a degree of abatement using pollution abatement expenditure. We accumulate pollution abatement capital expenditure and operating costs to a capital stock series. Pollution abatement capital expenditures is around 5 percent of total capital expenditure in manufacturing during the mid-1970s, increases to around 6.4 percent in the mid-1980ies, and even more in the late 1980ies. We adjust the capital stock figures downwards by subtracting pollution abatement capital expenditures from the gross investment series for the industries. Pollution abatement operating costs rise steadily through the period, doubling as a share of total manufacturing material inputs from 0.2 percent to 0.4 percent. The pattern for our industries is similar but at a higher level. Operating costs are between 0.3 and 1.9 percent of the value of material (lowest for textiles, highest for cellulose).

The change of the degree of abatement a(t) for a certain year t is determined by

$$(40) \qquad \frac{\Delta a}{\Delta t} = \gamma \frac{KA_t - KA_{t-1}}{KA_T - KA_0}$$

where KA_t is the real net capital stock of pollution abatement expenditures. KA_0 is the bench mark for the first year (1975), KA_T is the stock of the last year (1992) and γ is a parameter between 0 and 1. The stock of pollution abatement expenditures is calculated by

$$(41) \qquad KA_t = KA_{t-1} + IA_t - \delta\, KA_{t-1}$$

where IA_t is real abatement costs and δ is the rate of replacement (e.g. $\delta = 0.1$). If for an industry or for manufacturing IA_t is published in a statistical yearbook, KA_t can be calculated.

Formula (40) has the property that there will be no enforcement in environmental policy if $IA_t = \delta KA_{t-1}$. If real expenditure replaces only scrapped equipment, then the degree a(t) does not change. If net expenditure is positive, a(t) will increase. The accumulation of (40) implies

$$(42) \qquad \sum_{t=1}^{T} \frac{\Delta a}{\Delta t} = \frac{\gamma}{KA_T - KA_0} \sum_{t=1}^{T} (KA_t - KA_{t-1}) = \gamma .$$

Since a(T) - a(0) = γ, we interprete γ to be the degree of abatement in the final year, by assuming a(0) = 0 in 1975, the first year in our data set. If a(0) is known, then (42) becomes

$$a(T) = a(0) + \sum_{t=1}^{T} \frac{\Delta a}{\Delta t} .$$

For Germany the source for determining γ in (40) was the law[3] from 1983 which sets ambient air quality standards for air pollution. In this clean air act new machinery burning fossil fuel had to comply with a standard of $\gamma \geq 0.7$ for SO_2. This degree of abatement is mendatory for all (new and old) fossil fuel burning equipment by 1993. Hence it is γ = a(T) = 0.7 in 1992. The degree of abatement, calculated according to (42) shows the reluctance of retrofitting old burning equipment to the standard.

Feasibility and costs of the installation of end-of-pipe abatement measures depend on the pollutant and on the underlying production technology. Based on data collected by Friedrich (1990), it was possible to estimate abatement cost functions for SO_2 and NO_X disaggregated into 11 industries and into one household group. As expressed by (39) we assume constant returns to scale in abated emissions $a \cdot e \cdot E$ for a firm's aggregated abatement technology but assume that costs per unit of abated emissions are convex in the degree of abatement. The marginal abatement cost function has been specified as

$$(43) \qquad c'(a) = \beta(1 - a)^{\gamma}, \quad \beta > 0, \gamma < 0.$$

Integrating this function gives the unit cost function. The parameters β and γ have been estimated using yearly data for c'(a) and a.

$$c(a) = \frac{-\beta}{1 + \gamma} (1 - a)^{\gamma+1} + k.$$

[3] Bundesimissionsschutzgesetz (BIM SCH G)

As we have observations for c(a) for a certain a(t), we can calibrate the constant[4] k. We find that marginal abatement cost curves are fairly flat over the range of lower degree of abatement, but eventually begin to rise steeply as the degree becomes increasingly higher. This is in line with findings by Oates et. al. (1989) who estimated marginal abatement cost curves for controlling air pollution. Appendix 1 shows the marginal cost functions for the electricity sector.

After evaluating the abated and actual emissions the model computes the deposition of the pollutants per country and the resulting damage. The modelling of transboundary air pollution is linearized by using transport matrices. The deposition a country k receives from own and foreign activities is then

(44) $$DP_{p,k} = \sum_{c} t_{p,c,k} \cdot EM_{p,c} + DP^{0}_{p,k}$$

where $EM_{p,c}$ are the total emissions of pollutant p in country c, $t_{p,c,k}$ is the transport-coefficient form country c to country k and $DP^{0}_{p,k}$ is the background deposition.

For the calculation of damages five damage categories are distinguished (namely: acidification impacts on public health, acidification impacts on forests, acidification impacts on lakes, acidification impacts on materials and global warming impacts). The damage in a category is linked to the level of deposition and the level of total emissions. Damages in forestry, for instance, are mainly linked to the deposition of SO_2 and NO_X while damages in public health are linked to the ambient concentration of SO_2, which is usually close to the source of emission. Hence, these damages are assumed to be proportional to the emissions. The global warming effect of greenhouse gases like CO_2 is combined with the ambient concentration as well. There is no deposition of CO_2. Total damages of category l in country k are then

(45) $$DAM_{k,l} = \sum_{p} \phi_{k,l,p} \cdot DP_{p,k} + \sum_{c,p} \varphi_{k,l,p} \cdot EM_{p,c}$$

where $\phi_{k,l,p}$ *and* $\varphi_{k,l,p}$ are damage coefficients which were drawn from the literature.

[4] The calculations for chemicals are given in Appendix 3.

4. Tradable CO_2 emission permits within branches and / or EU member states

According to a system of tradable CO_2 permits, an environmental agency of a country or of the EU defines desired CO_2 emission volumes for a sequence of years and issues emission permits. We assume that CO_2 permits are first distributed free of charge on the basis of the industry's (or country's) base year emissions. Then we assume that the CO_2 emissions of the base year have to be reduced by 10% in that year. Thus there will be a demand for permits with a positive price for them. Depending on the cost of substitution and avoidance, and on the level and differences in growth rates, some branches (countries) will purchase permits and some will offer them for sale. Since no retention technologies are available for CO_2 at reasonable costs, the cost of disposal corresponds to that of substitution in changing from the old least cost approach to a new solution involving higher costs of production. The advantage of a system of tradeable permits is that cost effectiveness is achieved, i.e. the marginal cost of substitution and avoidance incurred by the polluters is harmonized within firms, branches of industry and regions. The optimum procedure is to avoid emissions as long as the marginal cost of reduction is lower than the price of a permit. The amount of CO_2 produced by a firm or country can be relatively easy determined in view of the constant ratio between the carbon content of fossil fuels and the CO_2 emissions produced during their combustion. A basis for assessment is obtained by multiplying the amounts of coal, oil and natural gas by their respective emission coefficients (converted into tonnes of CO_2 per real fuel input in million DM). The fuel input prices will then increase by $p \cdot e_i$, p being the permit price and e_i the emission coefficients for coal ($i=1$), oil ($i=2$) and gas ($i=3$).

When introducing permits free of charge and then choosing a desired level of CO_2 which is 10 percent below the base year case, two offsetting sales and purchase effects occur. Our figure which is based on a 20% reduction of CO_2, shows the net result of a trade in permits. MAC_i (E_i) are the marginal abatement costs (or cost of substitution and avoidance in case of CO_2) for an industry i or a country i, $i = 1, 2$. MAC has nothing to do with the abatement cost function $c(a) \cdot a$, given in section 3. MAC reflects the allocative losses in terms of substitution away from the former minimal cost combination. MAC(E) is the aggregate marginal abatement cost function with $E = E_1 + E_2$.

We assume that the firms have emitted E_1^P and E_2^P, respectively; i.e. they

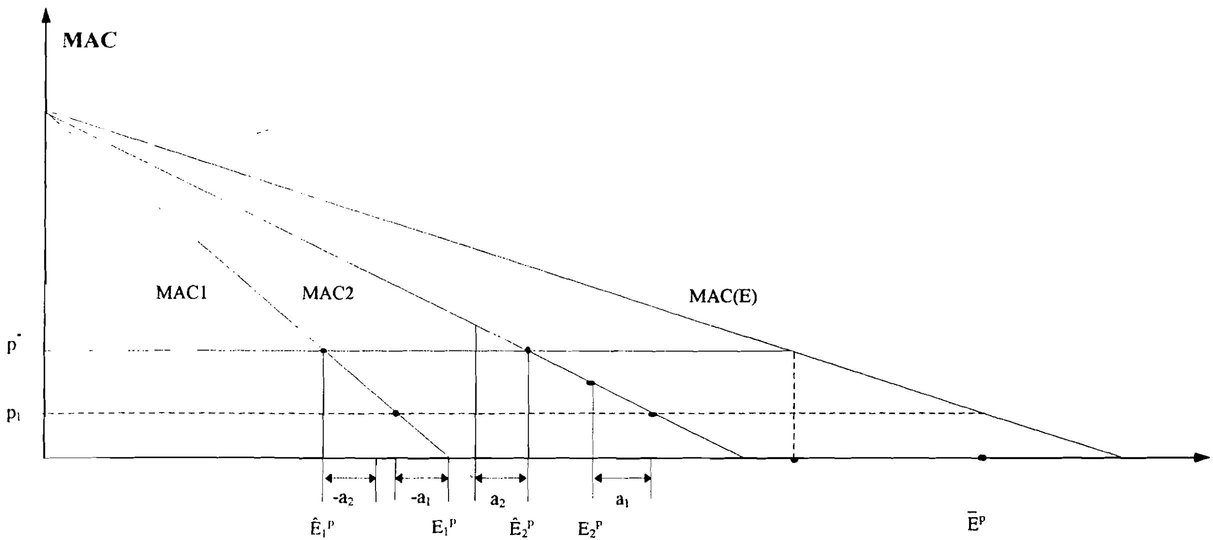


Fig. Distribution of tradable permits free of charge to firm 1 (E_1^P) and firm 2 (E_2^P) with an depreciation by 20 percent thereafter have been confronted with different standards. Each firm then holds tradable permits equivalent to E_i^P. Adding $E_1^P + E_2^P$ gives $\bar{E}^P$. Immediately after the issue of permits they are depreciated by 20 percent. In the figure the dotted lines refer to the costless issue of permits. Without a restrictive carbon policy, firm 2 would reduce its effort to avoid CO_2 emissions whereas firm 1 would have an incentive to avoid CO_2 emissions. It could sell these permits ($- a_1$) to firm 2 ($+ a_1$). However, given the more restrictive CO_2 policy in terms of $0.8\,\bar{E}^P$ permits, the permit price will raise to p^*. Due to the devaluation, firm 2 holds 8 instead of the required 10 units of permits. It avoids some CO_2 and buys the additionally needed permits ($+ a_2$) from firm 1. Firm 1 in turn holds after depreciation 6 units instead of 7.5 units of permits. But for firm 1 it is profitable to avoid a_2 units and sell them to firm 2($+ a_2$). The optimal allocation of CO_2 avoidance requires that marginal cost of avoidance corresponds to the permit price, i.e.

$$MAC_i\,(\hat{E}_i) = p^* \qquad for\ i = 1,2$$

where $\hat{E}_i$ denotes the corresponding emission. At the permit price p^* the market is cleared:

$$\hat{E}_1 + \tilde{E}_2 = \bar{E}^P \cdot 0.8$$

The net benefit of a cost-benefit calculation for industry i consists of the cost of avoidance AC_i and the cost (+) or revenue (-) resulting from the purchase or sales of permits. This yields $\quad AC_i\,(\hat{E}_i) + p^*\left[\hat{E}_i - 0.8 \cdot E_i^P\right]$

If we would have considered the introduction of a tradable permit system for SO_2 emissions, it would have been possible to calculate the welfare gain from a transition to a permit system issued free of charge. This is so because we have calculated abatement costs per industry, consisting of expenditure for abatement activities and of investment in abatement measures. Hence we have marginal abatement costs which differ across industries. A tradable permit system which guarantees the present air quality of SO_2 would result in a welfare gain and in a trade in permits.

The next step could then be one to a stricter enforcement in SO_2 emissions with the effects illustrated by the figure. For CO_2, however, costs of avoiding carbon dioxide are not available. They might be zero for households and other non-regulated industries and positive for the electricity producers. We therefore had to assume zero marginal cost of avoiding CO_2 for all industries, i.e. we start with a situation illustrated by points on the E-axis. For the empirical results our assumption implies that we underestimate welfare gains and overestimate welfare losses.

We first simulated the 10 percent carbon reduction policy country by country; i.e. countries reduce CO_2 simultaneously by 10% each. The model covers:

- 11 countries (BE - Belgium, DE - Germany, DK - Denmark, FR - France, GR - Greece, IR - Ireland, IT - Italy, N - The Netherlands, PO - Portugal, SP - Spain and UK - United Kingdom.
- 11 products and sectors: 1 - agriculture, 2 - coal, 3 - crude oil and refined oil products, 4 -gas, 5 - electric power, 6 - energy intensive industries, 7 - equipment goods industries, 8 - consumer goods industries, 9 - transport, 10 - services, 11 - non-market services.

The model considers full competitive equilibrium in all markets, excluding the labour market which is restricted by fixed labour supply and a periodically fixed wage rate. Unemployment is computed as residual. The exchange rate is kept fixed and the model allows for a free variation of the balance of payments. Concerning the CO_2-permits, the number of permits required for fossil fuel differs by the type of fuel according to different emission coefficients. Hydro and nuclear power plants therefore do not need permits.

Our measure of welfare change is based on Hicks' measure of equivalent income variation (EV). Since we have calculated the economic effects from introducing CO_2-permits only for one year we have not employed an intertemporal EV. We also have decided not to evaluate higher unemployment as leisure; that is we kept leisure LJ and the wage rate constant. Our EV is therefore based on the expenditure function in (24) and follows from:

$$EV = e(p^0, u^1, Z^0) - e(p^0, u^0, Z^0).$$

It gives the change in expenditure at the base case price vector p^0 and durables Z^0 that would be equivalent to the policy-implied change in utility. The utility function which corresponds to our expenditure function is

$$u = \prod_{i=1}^{n} (C_i - C_{0,i})^{\beta_i} \prod_{i=1}^{3} (Z_j - Z_{0,j})^{\gamma_j}$$

If EV < 0, welfare after the policy measure is lower than in the base case. The consumer would be willing to pay the maximum amount EV at the fixed bugdet level $e^0 = e(p^0, u^0, Z^0)$, to avoid the decline of utility from u^0 to u^1. Similarly, if EV > 0, the consumer would be willing to pay the maximum amount EV to see the change in environmental policy implemented.

6. Empirical Results

Table 1 presents the economic impact from a ten percent CO_2 reduction under a non-coordinated environmental policy. The national models are linked by trade flow matrices and a non-coordinated CO_2 policy means that each of the 11 countries reduces carbon dioxid by exactly 10 percent.

The first column of Table 1 shows the equivalent variation in mill. ECU. Of interest are especially the signs which turn out to be negative for all countries except Portugal. Germany, e.g. is willing to pay at the most about 1.5 billion ECU to see such a policy to be not implemented. This is about 0.2 percent of nominal GDP, as presented in column 3. There is, however, one country, Portugal, which has a positive EV. A Portuguese is willing to pay up to 1.5 ECU for the higher standard of living under a CO_2 reduction policy. Such a result indicates that marginal costs of avoiding CO_2 are rather low, the energy intensity in some branches is high and substitution of labor for energy is a significant source of higher income (see the one percent increase in employment for Portugal).

We next compare the proportionality between EV and GDP to have a crude measure for the distributional impact of a CO_2 reduction policy. It reflects the national sacrifices and approximates the marginal utility of income. This can be seen by comparing the EV on a per capita base. The willingness to pay per capita for not having a CO_2 reduction policy is highest in Denmark and lowest in Spain. Column 3 shows the percentage of EV in GDP as a measure of welfare gain or loss in relation to the income situation. Although EV per capita is the same for Italy and the Netherlands, the EV per GDP in column 3 express the real sacrifice compared to the money measures in column 2.

The figures in column 4 are the net result of changes in the components of the GDP calculation. For all countries, except Germany, Greece and the UK, we observe a growth in real GDP. To explain this outcome we first recognize from column 7 that for the losing countries private consumption is lower under a CO_2 policy. This is obvious, of course, given the formula for the EV. For the same reason, private consumption is higher for a winning country. Furthermore, gross domestic production is lower for all countries (column 6).

The variation in the rate of inflation (column 5) reflects the impact from higher energy prices, from a change in the user cost of capital, and from imported inflation. If relative prices and national GDP growth rates change, the trade flow matrices for each of the products transmit this effect. Column 8 and 10 show the change in national exports and imports. Import declines by all countries. One reason is the reduction in fossil fuel imports due to higher energy prices. Another one is the decline in private consumption. For all countries imports decline by a higher percentage than exports (e.g. Belgium, Ireland, Italy, Spain). This will have a positive net effect on the balance of trade which partly explains the measured growth in real GDP. A lower import volume for the EU implies a lower export volume for the rest of the world.

For most countries investment increases. The closure rule which balances GDP from the flow of cost approach and from the flow of product account produces a lower interest rate which stimulates investment.

The effect of the CO_2 policy on employment is positive except for Greece and the UK. There is a substitution effect away from energy to labour which is partly offset by a negative output effect if production declines. The latter effect is highest for Greece and the UK and dominates the positive substitution effect.

Column 13 finally shows an average permit price of 24 ECU per ton of CO_2 and a group of countries with a lower price (e.g. Greece and Belgium) and a group with a higher price (e.g. Denmark and Italy). The level of the permit price depends on country-specific emission coefficients, on the energy intensity, on the energy mix and on the cost of avoiding CO_2, i.e. the elasticities of substitution.

To summarize, the reason for the national differences in the impacts of a CO_2 policy is the different structure of the economies in terms of different weights of the energy intensive industries, of the service sector, of the composition of exports and imports or the difference in equipment with consumer durables. All these factors imply a different slope of the marginal cost curve of avoiding CO_2. Under our non-coordinated policy simulation the price of a permit differs considerably across countries. Since CO_2 is a global pollutant, a cost-efficient carbon reduction policy calls for a uniform CO_2 permit price for all EC countries. This policy will be introduced in the next section.

First, however, we show in Table 2 which sectors will buy permits and which will sell them. Sectors with a negative value offer permits because energy substitution is easier for them compared to those which demand permits. In all countries electricity and the energy intensive industries sell permits. Less emission intensive industries like services or industries not regulated in the past like transport or households are mostly better off if they decide to buy permits instead of practising substitution. Since the relative price of energy increases, demand will be restructured towards lower growth of energy intensive products and higher growth of those industries producing less energy intensive products.

Also for this reason energy intensive industries supply permits and growing industries, although less energy intensive, demand permits. However, not all of the emission-intensive industries will sell permits. For examples, the refineries (oil), agriculture, and transport will purchase permits because this is less expensive than the substitution of labour and of non-energy for energy (see Conrad and Wang (1994) for similar results). For the other branches, purchases and sales differ country by country depending on the composition of industries making up the branch. Households buy permits but in ECU per capita their expenses are very low. A family of 4 persons spends 22 ECU in France and 6 ECU in Spain.

Table 3 finally presents the economic impact of a tradable permit system under a coordinated policy of reducing CO_2 by 10 percent for the EU as a whole. The uniform permit price is 23 ECU which is about the average of the different permit prices obtained under a non-coordinated policy. The fact that it is lower by 1 ECU (23 instead of 24.15) reflects already the welfare gain from a coordinated policy. We expect a lower equivalent variation for the EU in total (-6491 ECU versus -7268 ECU for the non-coordinated case). EV in ECU per capita drops from -22.6 to -20.2. The sacrifice in the standard of living is lower if the actions are coordinated. From the perspective of a single country, not all benefit from the coordination. The EVs' in Table 3 are more negative for Belgium, for Germany, or for the Netherlands. Countries which benefit are Denmark, France or Great Britain. For Italy, e.g., the EV in ECU per capita is 33 percent lower (-16.5 instead of -24.9). In principle, countries with a steeper marginal cost of avoidance curve should be better off under a coordinated CO_2 policy whereas countries with a flatter marginal cost curve should be worse off. These are the countries which had a permit price below 24.15 ECU in Table 1. Private consumption is now lower by 0.31 percent on the average compared to 0.34 in Table 1.

The economic variables reflect this result because the decline in production is now higher for those countries which are worse off under a coordinated policy. Although private consumption is now lower by only 0.31 percent on the average compared to 0.34 in Table 1, only the consumers of countries with a former higher permit price benefit. Those countries avoid now less than 10% of CO_2 whereas the other countries avoid now more than 10% of CO_2. The revenues from selling permits to the former high-permit price countries does not compensate the consumers of the former low-permit-price countries for their higher effort in avoiding CO_2 for the EU member states. An exception is Greece which benefits from the sale of higher priced permits to permit demanders. The rest of the world also benefits from the economic impact of a coordinated CO_2 policy because total EU import demand declines less under such a policy (-0.9 compared to -1.01).

Table 4 shows who will be an exporter or importer of permits. Countries with a permit price from the non-coordinated policy below the uniform price of 23 ECU are an exporter of permits. On the permit market electric utilities and the energy intensive industries are the main supplier of permits, and households and transportation the main demander.

We finally have simulated an unilateral CO_2 reduction policy by a single country, Germany. Compared to the 10% reduction under a non-coordinated policy the EV expresses a willingness to pay additionally 278 mill. ECU at the most for not having an unilateral CO_2 policy. Most other countries benefit from this policy because their EV is positive. Since the impact on domestic prices is rather small (0.09%), the impact on exports is small too. If we compare the results under an unilateral CO_2 policy with those obtained under a coordinated policy (Table 3), the EV is about the same. However, under that policy Germany is reducing 11,2% and should be better off as sidepayments are provided for under a coordination.

7. Conclusion

Any attempt to solve global pollution makes the linkage between energy and the environment evident. National differences in environmental concern, in affectedness, in per capita income and the free-rider situation delay a coordinated action. Cooperation is much easier if there exists a good substitute for a pollutant as in the case of FCKW. But for fossil fuel no substitute is in sight in the near future. Our simulations have shown that there is no free lunch in having lower CO_2 emission levels. A unilateral policy by a single country is - in economic terms - less attractive as an action by all EU member states. But the difference in costs seems to be rather low. A common EU permit market could reduce the loss in welfare, measured in terms of equivalent variation, by 10.7 percent. If the difference in the equivalent variation under a non-coordinated policy and under a cooperative policy could be used as sidepayments to agree to a cooperative CO_2 policy, then countries which should obtain sidepayments as compensation for the reduction in welfare are (in million ECU): Belgium (120), Germany (286), Ireland (23), Netherlands (12), Spain (14). Countries which gain from a cooperative policy and therefore have to pay are Denmark (-185), France (-57), Greece (-13), Italy (-478), Portugal (-2), and Great Britain (-502). The winning countries (their total gain is 1237) have to pay to the losing countries the amount of 455 mill. ECU and the amount left is the difference in the equivalent variations for the two simulations.

Our objective has been to show that the cost of a CO_2 policy can be expressed in economic magnitudes. The benefits with respect to the greenhouse gas problem of such a policy are more difficult to estimate and should be higher than the costs we obtained in order to justify a CO_2 reduction policy. Our future work will focus on this aspect using an integrated assessment framework.

Table 1: The impact of tradable permits under a non-coordinated environmental policy

Scenario: 10 % reduction of carbon dioxide in each country

	EV in Mill. of ECU	EV in ECU per capita	EV per GDP in %	GDP (%)	GDP deflator (%)	production (%)	priv. cons. (%)
Belgium	-60	-6.05	-0.06	0.09	0.33	-0.09	-0.09
Germany	-1449	-23.75	-0.20	-0.09	0.12	-0.24	-0.28
Denmark	-359	-70.23	-0.55	0.06	0.20	-0.17	-0.85
France	-1360	-24.72	-0.23	0.00	0.13	-0.15	-0.32
Greece	-63	-6.39	-0.08	-0.22	-0.23	-0.33	-0.10
Ireland	-62	-17.47	-0.31	0.01	0.45	-0.06	-0.42
Italy	-1424	-24.92	-0.27	0.08	0.25	-0.14	-0.41
Netherlands	-362	-24.97	-0.24	0.01	-0.13	-0.13	-0.37
Portugal	16	1.56	0.06	0.44	1.49	-0.16	0.09
Spain	-182	-4.71	-0.09	0.06	0.63	-0.22	-0.13
Great Britain	-1963	-34.66	-0.38	-0.10	-1.20	-0.54	-0.53
EU	-7268	-22.61	-0.24	-0.02	-0.05	-0.25	-0.34
Rest of World	-	-	-	-	-	-	-

	exports (%)	invest. firms (%)	imports (%)	employ. (%)	wage rate (%)	permit-price (ECU/ton CO2)	CO2-reduction (%)
Belgium	-0.16	0.35	-0.26	0.15	0.00	10.64	-10.00
Germany	-0.07	-0.03	-0.35	0.05	0.00	19.97	-10.00
Denmark	-0.12	0.05	-1.27	0.31	0.00	47.28	-10.00
France	-0.09	0.05	-0.72	0.12	0.00	24.83	-10.00
Greece	-0.34	-0.18	-0.69	-0.21	0.00	10.22	-10.00
Ireland	-0.10	0.05	-0.44	0.22	0.00	19.19	-10.00
Italy	-0.13	0.10	-1.37	0.32	0.00	35.99	-10.00
Netherlands	-0.06	-0.27	-0.46	0.21	0.00	22.18	-10.00
Portugal	-0.41	1.05	-0.88	1.09	0.00	23.65	-10.00
Spain	-0.42	0.27	-1.01	0.43	0.00	20.56	-10.00
Great Britain	0.11	-1.37	-0.96	-0.29	0.00	31.12	-10.00
EU	0.01	-0.22	-1.01	0.12	-	25.10	-10.00
Rest of World	-1.01	-	0.01	-	-	-	-

Table 2: Purchase (+) and sales of permits (-) under a non-coordinated environmental policy

(in millions of ECU)

	Belgium	Germany	Denmark	France	Greece	Ireland
agriculture	1.06	13.17	-2.89	9.63	2.09	1.17
coal	-1.22	-8.01	0.00	-10.82	-0.11	-0.01
oil	3.39	20.36	1.36	17.61	0.48	0.06
gas	0.01	4.43	0.94	0.57	3.04	1.29
electricity	-4.64	-178.45	-44.87	-120.76	-12.76	-2.49
energy intensive industries	-44.10	-286.61	-10.91	-254.54	-9.26	-15.66
equipment goods industries	0.48	0.79	-0.73	-8.74	-0.06	-0.38
consumer goods industries	2.93	20.50	-5.62	9.13	1.71	-0.02
transport	3.33	29.82	5.75	34.54	2.95	0.90
services	8.01	30.55	0.10	19.00	1.82	0.33
non market services	0.86	12.73	-1.01	3.51	0.93	-0.47
households	29.88	340.71	57.88	300.85	9.18	15.26
net EU trade volume	0.00	-0.01	0.00	0.00	-0.01	0.00

	Italy	Netherlands	Portugal	Spain	Great Britain	EU	
agriculture	1.10	-0.83	-0.13	4.17	7.42	35.94	
coal	-14.19	0.00	-0.42	-1.67	-5.68	-42.12	
oil	16.17	20.57	0.98	8.89	28.51	118.40	
gas	0.07	0.76	0.00	0.12	19.95	31.17	
electricity	-73.64	-60.22	1.02	-36.50	-216.27	-749.58	
energy intensive industries	-305.71	-48.20	-10.20	-61.17	-147.66	-1194.02	
equipment goods industries	-5.30	-0.34	-0.15	-2.27	-22.66	-39.37	
consumer goods industries	13.62	2.11	-0.96	5.32	-30.38	18.35	
transport	45.39	9.40	2.27	23.03	51.56	208.96	
services	12.07	0.76	0.19	6.32	12.84	91.99	
non market services	0.26	-2.05	-0.18	0.78	-1.34	14.01	
households	310.14	78.03	7.60	52.98	303.72	1506.22	
net EU trade volume	-0.01	-0.01	0.00	0.00	0.00	-0.03	truncation error

Table 3: The impact of tradable permits under a coordinated environmental policy

Scenario: 10 % EU-wide reduction of carbon dioxide

	EV in Mill. of ECU	EV in ECU per capita	EV per GDP in %	GDP (%)	GDP deflator (%)	production (%)	priv. cons. (%)
Belgium	-180	-18.29	-0.18	0.13	0.76	-0.14	-0.26
Germany	-1735	-28.43	-0.24	-0.11	0.17	-0.27	-0.33
Denmark	-174	-34.07	-0.27	0.06	0.06	-0.08	-0.41
France	-1303	-23.68	-0.22	0.00	0.12	-0.15	-0.31
Greece	-50	-5.04	-0.06	-0.03	0.49	-0.17	-0.08
Ireland	-85	-24.09	-0.43	-0.01	0.54	-0.10	-0.57
Italy	-946	-16.56	-0.18	0.06	0.13	-0.11	-0.27
Netherlands	-374	-25.81	-0.25	0.01	-0.12	-0.13	-0.38
Portugal	14	1.42	0.06	0.43	1.45	-0.16	0.08
Spain	-196	-5.07	-0.10	0.08	0.75	-0.23	-0.14
Great Britain	-1461	-25.81	-0.28	-0.08	-1.05	-0.43	-0.39
EU	-6491	-20.19	-0.21	-0.02	0.00	-0.23	-0.31
Rest of World	-	-	-	-	-	-	-

	exports (%)	invest. firms (%)	imports (%)	employ. (%)	wage rate (%)	permit-price (ECU/ton CO2)	CO2-reduction (%)
Belgium	-0.18	0.66	-0.41	0.39	0.00	23.06	-17.04
Germany	-0.07	-0.03	-0.41	0.07	0.00	23.06	-11.20
Denmark	-0.08	0.02	-0.71	0.16	0.00	23.06	-5.69
France	-0.08	0.04	-0.69	0.11	0.00	23.06	-9.51
Greece	-0.35	0.57	-0.37	0.31	0.00	23.06	-17.15
Ireland	-0.11	0.05	-0.55	0.27	0.00	23.06	-11.55
Italy	-0.11	0.06	-1.00	0.20	0.00	23.06	-7.32
Netherlands	-0.06	-0.28	-0.48	0.23	0.00	23.06	-10.27
Portugal	-0.40	1.02	-0.87	1.07	0.00	23.06	-9.83
Spain	-0.43	0.32	-1.07	0.51	0.00	23.06	-10.95
Great Britain	0.04	-1.14	-0.80	-0.26	0.00	23.06	-7.89
EU	0.00	-0.16	-0.90	0.13	-	23.06	-10.00
Rest of World	-0.90	-	0.00	-	-	-	-

Table 4: Purchase (+) and sales of permits (-) under a coordinated environmental policy

(in millions of ECU)

	Belgium	Germany	Denmark	France	Greece	Ireland
agriculture	0.11	11.25	1.06	9.90	1.44	1.05
coal	-5.90	-11.48	0.00	-9.28	-0.49	-0.01
oil	6.72	22.35	1.06	16.61	0.93	0.07
gas	0.02	3.30	1.06	0.57	7.14	1.26
electricity	-45.59	-278.44	-0.22	-102.92	-83.27	-4.46
energy intensive industries	-222.27	-405.19	-0.68	-217.32	-47.41	-21.89
equipment goods industries	-1.44	-5.58	0.40	-6.53	-0.52	-0.66
consumer goods industries	2.26	16.89	1.17	10.50	1.51	-1.89
transport	5.62	29.93	8.25	33.46	4.69	0.85
services	3.23	26.89	2.49	20.59	1.60	-0.04
non market services	-1.92	8.27	1.38	5.24	0.54	-0.93
households	61.58	388.53	30.19	280.39	20.19	17.65
net EU trade volume	-197.59	-193.27	46.16	41.21	-93.64	-8.99

	Italy	Netherlands	Portugal	Spain	Great Britain	EU	
agriculture	5.25	-1.52	-0.03	2.95	9.47	39.88	
coal	-6.34	0.00	-0.40	-2.17	-2.73	-38.80	
oil	13.33	20.06	0.98	9.66	22.20	113.89	
gas	0.10	0.77	0.00	0.13	36.66	49.76	
electricity	-0.47	-65.16	1.13	-54.90	-50.77	-680.62	
energy intensive industries	-114.93	-52.12	-9.58	-82.06	-69.03	-1220.59	
equipment goods industries	2.47	-0.53	-0.13	-3.35	-8.17	-23.37	
consumer goods industries	15.85	1.75	-0.80	3.60	-7.78	44.94	
transport	42.17	9.51	2.28	23.37	46.30	205.58	
services	32.45	0.28	0.30	4.12	25.69	117.63	
non market services	8.56	-2.64	-0.15	0.04	13.41	32.72	
households	206.44	80.81	7.42	59.14	233.66	1368.36	
net EU trade volume	204.88	-8.80	1.00	-39.48	248.92	0.40	truncation error

Table 5: The impact of tradable permits under a unilateral action by Germany

Scenario: 10 % reduction of carbon dioxide in Germany

	EV in Mill. of ECU	EV in ECU per capita	EV per GDP in %	GDP (%)	GDP deflator (%)	production (%)	priv. cons. (%)
Belgium	10	1.04	0.01	0.00	0.02	0.00	0.01
Germany	-1727	-28.30	-0.23	-0.09	0.09	-0.25	-0.33
Denmark	4	0.80	0.01	0.00	0.00	0.00	0.01
France	44	0.80	0.01	0.00	0.01	0.01	0.01
Greece	-3	-0.29	0.00	-0.01	-0.01	-0.01	0.00
Ireland	5	1.38	0.02	0.01	0.01	0.02	0.03
Italy	4	0.08	0.00	0.00	0.00	0.00	0.00
Netherlands	-2	-0.12	0.00	-0.01	-0.01	-0.02	0.00
Portugal	1	0.08	0.00	0.00	0.01	0.00	0.00
Spain	3	0.08	0.00	0.00	0.00	0.00	0.00
Great Britain	33	0.58	0.01	-0.02	-0.10	-0.01	0.01
EU	-1628	-5.06	-0.05	-0.03	0.01	-0.07	-0.07
Rest of World	-	-	-	-	-	-	-

	exports (%)	invest. firms (%)	imports (%)	employ. (%)	wage rate (%)	permit-price (ECU/ton CO2)	CO2-reduction (%)
Belgium	-0.04	0.02	-0.03	0.01	0.00	0.00	0.35
Germany	-0.02	-0.05	-0.40	0.05	0.00	19.45	-10.00
Denmark	-0.01	0.00	0.00	0.00	0.00	0.00	0.12
France	0.00	0.01	0.01	0.01	0.00	0.00	0.12
Greece	-0.02	-0.02	-0.03	-0.01	0.00	0.00	-0.01
Ireland	0.01	0.02	0.03	0.00	0.00	0.00	0.17
Italy	-0.02	0.00	-0.01	0.00	0.00	0.00	0.02
Netherlands	-0.06	-0.02	-0.06	-0.01	0.00	0.00	0.02
Portugal	-0.01	0.01	0.00	0.00	0.00	0.00	0.04
Spain	-0.03	0.00	-0.02	0.00	0.00	0.00	0.01
Great Britain	-0.06	-0.12	-0.05	-0.03	0.00	0.00	0.06
EU	0.00	-0.04	-0.13	0.01	-	-	-2.74
Rest of World	-0.13	-	0.00	-	-	-	-

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Appendix 1: Construction of the Marginal Abatement Cost Function

In GEM-E3 we distinguish between thirteen emittants: agriculture, coal, oil, gas, electric power, energy intensive industries, equipment goods industries, consumer goods industries, transport, services, non-market services, heating systems of households and private traffic. The available data[1] concerning abatement measures for SO_2 and NO_x is usually collected under the criterias "type" and "size" of the combustion systems. If we aggregate some GEM-E3 industries, we can keep the consistency of the data and obtain 5 emission groups.

group of emittants	GEM-E3 industries
1	electric power
2	energy intensive industries, coal and equipment goods industries
3	oil (refineries)
4	consumer goods industries, gas, services, non-market services, agriculture and heating systems of the households
5	transport and private traffic (households)

Using these cost functions for all countries, implies the following assumptions:

1) Availability of the considered abatement technology all over Europe.

2) The installation of this technology is feasible in all countries.

3) Equal installation costs for all countries.

There is no better country specific data available (in particular not for end-of-pipe technologies). Therefore even more technical oriented models use these assumptions. The impacts of abatement activities actually observed after 1985 are computed in a reference run of the model by taking this emission reduction paths as an exogenous input to the model.

For electric power generation, for instance, we constructed the following marginal abatement cost functions in DM per kg of abated emission.

[1] For this study we used the data collected by Friedrich (1990).

SO_2

marginal cost function $c'(a) = 1.717 \cdot (1-a)^{-0.592}$

unit cost function $c(a) = -4.208 \cdot (1-a)^{0.408} + 5.7$

NO_x

marginal cost function $c'(a) = 2.775 \cdot (1-a)^{-1.294}$

unit cost function $c(a) = 9.439 \cdot (1-a)^{-0.294} - 7.1$

Figure 1 shows the marginal abatement cost functions for electric power generation.

Figure 1: marginal abatement cost function of group 1 of emittants (estimated) in DM/kg