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The Effects of Carbon Taxation on Carbon, Nitrogen and Sulphur Pollutants in Europe: Combining General Equilibrium and Integrated Systems Approaches

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The effects of carbon taxation on carbon, nitrogen and sulphur pollutants in Europe: combining general equilibrium and integrated system approaches

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Abstract This paper outlines the development of a CGE model as a tool for analysing many of the issues relating to the introduction of environmental taxation, such as interaction with other taxes, revenue recycling, international carbon 'leakage' and tax export effects. The model is linked to IIASA's RAINS model to expand the analysis to cover other cross-boundary pollution.

Analysis of a 30 ECU per tonne carbon tax applied in Germany, the UK and the rest of the European Union indicate that it could achieve savings of the order of 20 per cent in carbon emissions compared to business as usual, at little economic cost to the EU countries. The emission savings may be slightly higher in Germany and lower in the UK than the rest of the EU, while the latter would also gain more from terms of trade effects. The tax would bring substantial savings in sulphur emissions. Alternatively, if emissions were allowed to stay constant, the saving on abatement technology would mean a modest improvement in the net cost of the tax. Effects on Nitrogen emissions are smaller.

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1 Introduction

At the Kyoto Conference in December 1997, the European Union (EU) agreed targets for reducing carbon dioxide (CO_2) emissions by 8 per cent of 1990 levels by the year 2010. Despite some expected favourable developments in fuel use and efficiency, overall expected economic growth means a cut is needed relative to "business as usual" forecasts for 2010 of about 11 per cent growth in emissions (Lord Marshall's Report to the UK government, 1998). There is therefore a role for a taxation or marketable permit policy to meet these goals. Such taxes/permits are bound to have effects on the terms of trade and real incomes, and since they affect patterns of fuel use they will also have effects on international pollution issues, such as the costs of acid rain pollution and its abatement.

This paper summarises the adaptation of a large, static, multi-country computable general equilibrium model (CGE) of the European Union, as set out in Fehr, Rosenberg and Wiegard (1995), henceforward referred to as the FRW model, to analyse the issue of environmental taxation. Section 2 outlines changes to the CGE model, to make it more suitable for energy analysis, as well as the development of a link to the International Institute for Applied Systems Analysis (IIASA)'s integrated environmental assessment model RAINS (Regional Acidification Information and Simulation), which helps identify the effects on other international pollutants. We believe this is the first time an integrated assessment model has been given a general equilibrium dimension: such models take energy consumption data as exogenously determined inputs, while GE models take as input more primitive variables such as technology , tastes and policy. Section 3 then summarises some of the simulations carried out on these models.

Reasons for a CGE approach.

Clarke et al (1996) discuss a variety of approaches to assess the likely costs of carbon abatement. The use of CGE models reflects a recognition that the effects of an environmental tax reform can spread well beyond the energy sector. They also produce a useful summary of the net effect in terms of standard measures of economic activity (real GDP or GNP) and welfare (equivalent variation). While traditional macroeconomic models may be useful in assessing transitional costs such as rates of unemployment or inflation, CGE models may be more relevant in assessing the long-term effects of action to combat global warming, since they allow for a greater degree of microeconomic adjustment.

Depending on their setup, CGE models can deal with a number of important aspects:
(i) *The interaction of a carbon tax with existing energy taxes and subsidies*. If a tax shifts demand away from subsidised industries, as Edwards (1998) found in the case of a carbon tax on subsidised German coal, the overall cost of the tax is reduced, while if it is applied to fuels already bearing high taxes and high profit mark-ups (see Clarke and Edwards, 1998), the cost of the tax will be increased. While the model in this paper, does not have the same detail of cross-subsidisation as in the above articles, it allows for subsidies on fuel production and different specific and ad valorem taxes on different fuels to different users.

(ii) *Uses of the recycled tax revenue.* There has been much comment on the possibility that by using carbon tax revenues to cut taxes on labour, European countries could actually gain a net economic benefit. However, studies using the general equilibrium approach (sometimes even with non-clearing labour markets – e.g. Conrad and Schmidt 1998) have generally dampened the early optimism about this ‘double dividend’ (see discussion in Boehringer, Pahlke and Rutherford, 1998), since in a general equilibrium framework taxes on production or consumption ultimately raise the cost of consumer goods. This reduces the value of work time against leisure time, and so has similar effects to an income tax in terms of deterring labour supply (see Bovenberg and de Moji, 1994).

Where income taxes are highly progressive, transferring taxation from income to consumption tends to encourage higher labour supply, though at the expense of worsened income distribution (though only a few CGE studies, such as Pench, 1998, actually look at distributional effects). If existing taxes are not progressive, there is only a gain if the initial tax system is poorly designed.

For a detailed description of the FRW model, including details of algebraic derivations and numerical solution, see Ruocco (1996). Duncan et al (1998) and Hutton and Ruocco (1999) have used a modified version of the FRW incorporating different types of labour supply and non-clearing labour markets to look at labour supply implications of tax switches. However, such a detailed treatment of labour markets has been omitted here, in order to allow for more detailed treatment of other aspects of the model. Nevertheless, the version of the model outlined in this paper does contain a positive labour supply elasticity, so the nature of revenue recycling will have important effects on labour supply, output and welfare. An equation listing is shown in the Appendix.

The international dimension of the problem in Europe

Much environmental policy is now decided jointly by European Union (EU) member states, which means that simulations based on action by a single country are not realistic. In addition, the environmental policies of EU member countries have substantial effects on their neighbours:

(i) *Carbon leakage*. Attempts by one country to reduce carbon emissions can be offset by shifts in production of carbon-intensive industries to other countries. In practice, as Boehringer, Rutherford and Voss (1997) find, leakages are only important in models using the Ricardo-Viner approach, under which goods produced by a particular production sector in different countries are perfect substitutes. Under the more common Armington approach, where goods from different countries are treated as qualitatively different, leakage effects are small. The Armington formulation is probably more plausible given that production sectors are relatively aggregated (and hence exports from one sector in different countries may consist of quite different commodities, such as French wine and Irish beef), and also given that there is considerable two-way trade within sectors in our database (something not consistent with the Heckscher-Ohlin/Ricardo-Viner assumptions [1].

(ii) *Tax export* (Markusen, 1975). Effects on world fuel prices, or on real exchange rates may mean that some of the cost of a carbon tax is borne by countries other than those imposing the tax. Global or North-South models (e.g. Whalley and Wigle (1991)), have looked at these effects in some detail. The terms of trade effect, where an energy-importing country imposing a carbon tax sees a reduction in its import bill and consequent rise in its exchange rate, has been large enough in some single-country studies - e.g. Germany in Edwards (1998), or Italy in Pench (1998) - to outweigh other effects and actually cause a rise in real incomes in the country imposing the tax, at least

[1]For more detailed discussion see Vocke (1998 forthcoming). The Armington assumption, where different countries' shares in demand for a particular good depend only on relative prices, is perhaps best seen as an approximation to deal with the many reasons why goods from different countries are imperfect substitutes. The formulation may not be the most appropriate in some cases (e.g. where economies of scale to the

for modest tax rates. Given that Germany and Italy both trade largely with their European neighbours, a multi-country model of Europe would seem a very appropriate way of assessing these effects further.

Many CGE studies have used models that rule out sizeable terms of trade effects: for example Boehringer et al's (1998) model of Germany, while using an Armington trade model, has fixed import and export prices[2]. In Conrad and Schmidt's 1998 European multi-country study, prices for Europe's trade with the rest of the World are fixed, so potential tax export effects to the rest of the World are effectively ruled out. By contrast in the FRW model all countries produce differentiated products, and while the trade effects are largest between European neighbours, which trade a great deal with one another, the rest of the World's import and export prices can also be affected by demand changes.

(iii) International pollution. Edwards (1998) finds sulphur dioxide (SO_2) emissions change by a very similar proportion to CO_2 in response to a carbon tax in both Japan and Germany (both pollutants being emitted in similar proportions from the main fossil fuels), while nitrogen oxides/ozone (NOx) are less affected by a carbon tax, and particulates are affected a good deal in Japan but less in Germany. Valuations based on estimates of health and environmental gains from savings in this pollution can be quite substantial relative to the other costs and benefits involved in carbon abatement (see Clarke and Edwards, 1997).

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firm are at the root of the imperfect substitution).

[2]In Boehringer et al's model, imports, whose price is fixed, are an imperfect substitute for German produce, while, for German producers, exporting (at a fixed world price) is an imperfect substitute for sales to the home market. Hence imports and exports will change as a tax is introduced, but Germany's terms of trade are unaffected.

Much of the cost of changes in pollution will be borne abroad. The costs of CO_2 emissions are worldwide, while those of SO_2 and NOx are spread regionally across Europe. Particulates tend to be more local, though with some international spread. Alternatively, if the country imposing a carbon tax has agreed to limit its emissions of these other pollutants to fixed target levels, the consumption of less polluting fuels can bring a saving in terms of less need to install abatement technology. In this case the saving is internalised. Conrad and Schmidt look at the latter possibility for SO2 and NOx, with rather simplified abatement cost curves.

2 Structure of the model and database

This study runs a multi-country CGE model of the European Union, developed from the FRW model, in conjunction with the RAINS model of transboundary SO_2 and NOx pollution and abatement costs.

For an energy/environmental study it was necessary to alter the disaggregation of the FRW database. In addition, there is an extra stage of the production function to allow for aggregation of energy and other goods. The indirect taxation structure is more sophisticated, but unlike the FRW original, government spending is not differentiated from household consumption. Aspects of the modelling that are altered from the original FRW model are marked with asterisks**.

There are four regions in the model: the UK, Germany, the rest of the (12 member 1992) EU and the rest of the world (ROW). There are 3 non-energy and 9 energy sectors. The latter are highly aggregated to allow for a more detailed disaggregation of energy. Output can be sold as an input to other sectors or to consumers at home or abroad. Consumers are an aggregate of households, government and various non-profit-making bodies. All sectors are perfectly competitive. Of the two factors of production, labour is mobile between sectors but not between countries, while capital can move freely around the world. As a result there is a single global cost of capital, while wages vary between countries.

Data Sources

Starting from Fehr's (1996) data set for 1992, it was necessary to disaggregate energy from an energy and water sector. For this reason, for European **energy sectors** we have used data from the International Energy Agency's *Energy Statistics of OECD Countries* and *Energy Prices and Taxes.* Average prices for the Rest of the EU were approximated by average of French and Italian prices. Accuracy of data for the Rest of the World (ROW) is not so important for this study. Energy production and use tables for ROW were based on Table A10 of the 1992 World Bank *World Development Report*, with prices and taxes assumed to be somewhat lower than in the EU. Trade volumes were derived from the total import and export figures by area.

The **non-energy sectors** have been highly aggregated from the original FRW model, into an energy-intensive sector (chemicals, steel and paper, pulp and printing), an agriculture, services and transport sector (no separate transport data was available in the FRW database), and an other industry sector.

Production function.

The basis of the model is a nested constant elasticity of substitution (CES) production function, with goods in the same stage of nesting being closer substitutes for one another.

(i) Imports from different countries are combined to form a single composite imported input. (ii) The composite imported input is combined with home-produced inputs. (iii)** Inputs are aggregated to form composite inputs of energy, non-energy materials and value added. (iv)** Energy, materials and value added are combined to form total output.

Consumer Sector and labour supply

For final consumption, again nested CES functions are exploited. The stages are:

(i) Merge imports of each commodity from different countries as a ces aggregate.

(ii) Combine the aggregate import with the home-produced version of the same good.

(iii) Aggregate the various consumer goods, to form aggregate consumption.

(iv) Disposable income is spent entirely on the aggregate consumer good. Household utility is a CES aggregate of consumption and leisure.

The government sector

Unlike the FRW model**, government **spending** is simply treated as a transfer to households. **Taxes** comprise the following. (1) On production: (i) A production tax/subsidy per unit of output and (ii)** Specific taxes per unit volume on inputs of energy into another industry. (2) On trade, import tariffs between the EU and non-EU countries. (3) On consumption (i) Specific taxes** and (ii) Value added taxes with variable rates across goods. (4) Income tax applies to both labour and capital income of a single representative household, with 'representative marginal income tax rates' derived from Hutton and Ruocco (1999).

International Trade

Trade is modelled using the "Armington specification", in which all countries produce differentiated goods. The household and government balances are fixed at zero, which implicitly fixes the balance of payments (trade plus long-term capital) at zero too. All elasticity assumptions are given in the Appendix Table 1.

Modelling energy consumption and carbon emissions.

The carbon calculations are basically derived from consumption of primary fossil fuels, for which the following carbon content figures are used (tonnes carbon per tonne of oil equivalent):

Hard coal 1.12 tC/toe

Soft coal 1.37 tC/toe

Crude oil 1 0.84 tC/toe

Natural gas 0.64 tC/toe

The carbon content of use of secondary fossil fuels is based upon the carbon from primary fossil fuels used in their calculation. Where the secondary fuel is an import, we use the total carbon content of primary fossil fuels used in the production of the secondary fuel.

The Carbon Tax is applied in ECU per tonne carbon to all primary fuels according to their *initial (base case) carbon content*, and to all imported secondary fossil fuels, if their country of origin is not also applying a carbon tax. No tax is applied to imported electricity.

Link to the IIASA RAINS model of sulphur and nitrogen emissions and deposition. RAINS, developed by IIASA (see Alcamo et al, 1990, Klaassen, 1996, Bertok et al 1993), is the most widely used model of emissions of sulphur dioxide (SO_2) and nitrogen oxides (NOx), and of their deposition and abatement costs. The model has sulphur and nitrogen modules, each of which uses scenarios combining an energy pathway (a set of projected demands by fuel, country and sector, for 5 year intervals) with an abatement scenario (based only on technological measures). For our work, the output from the CGE model, showing the effects of a carbon tax on fuel use, is used as the basis for a revised energy pathway. We are interested in the consequential geographical distribution of the two pollutants, SO_2 and NOx.

Combining the two models raises a number of complications. RAINS is a scenario model for a series of 5 year snapshots into the future, while the CGE solves for the energy economy in a single base year for alternative tax policies. We have therefore concentrated on looking at one year only in the RAINS pathways, 1995, which is reasonably close to the 1992 base for the CGE model, and using that as the base case for simulations. In addition, RAINS uses a greater disaggregation of fuels and sectors than the CGE model, with categories not agreeing exactly, so to apply the changes compared to base we have had to make assumptions as to which fuels and sectors in the CGE correspond to which in RAINS.

RAINS is also more disaggregated in terms of countries. The CGE 'Other EU12' grouping is split down into 10 individual member states for RAINS. The non-EU countries of Europe are all covered separately in RAINS, but form just part of the 'ROW' grouping in the RAINS model.

The base case shares of different fuels within a sector vary greatly between different member countries of Other EU12 and ROW. This can cause unrealistic effects (e.g. if oil is substituted for coal across the other EU12 group as a whole, countries which are oil-intensive may see fuel use rise in response to a tax, while countries which are coal-intensive will see it fall). This effect is reduced by alternately rescaling energy use by country and by sector.

3 Some carbon tax simulations

Appendix Table 2 shows some key statistics of our database in the base year 1992. The total EU accounts for 13.3 per cent of global carbon emissions. Of EU members, the UK and Germany, which are relatively more coal-dependent, produce 20 and 30 per cent respectively. The UK imports a very small fraction of its fuel. Germany imports about 2/3 of its primary energy needs, while the rest of the EU is almost totally dependent on imports. As a result, the terms of trade effect of a carbon tax is much more marked in the Other EU12 countries than in Germany or, particularly, the UK.

For simulation purposes, the chosen level of carbon tax is 30 ECU per tonne carbon (1992 prices). Appendix Table 2B calculates the *average* expenditure by all final users on energy, relative to the total carbon emissions of the country concerned. As can be seen, a 30 ECU/tonne tax is modest compared to 450-800 ECU expenditure per tonne carbon across the EU. But prices of some fuels to some sectors (e.g. of coal to power generation) will rise much more sharply.

A final comment on what to expect in this type of modelling exercise is in order: long-term CGE models tend to produce lower estimates for the costs of environmental taxes than shorter-run macroeconomic studies, since they allow more flexibility at a microeconomic level for the economy to adapt to the tax. For a carbon tax to produce a 'large' economic loss requires either a very high rate of tax, or that the tax compounds existing distortions in the economy.

Basic Simulations of a carbon tax (Appendix Table 3)

This study considers four scenarios: where carbon taxes are imposed in the UK alone, in Germany alone, in the rest of the EU-12 and across the EU. It is assumed the revenue is recycled as lower value added tax, which would have less of a labour market effect than recycling as income tax, but should be more equitable in terms of income distribution (which we cannot analyse, but see Barker and Kohler (1998)). This paper is not intended specifically to investigate a 'double-dividend' effect of reducing labour taxes, although as all taxes in this model affect the work decision, labour market effects mean that the efficiency effects of changes in the incidence of indirect taxes are amplified.

Column A shows the effects of a 30 ECU carbon tax in the UK. Perhaps surprisingly the carbon tax at 30 ECU/tC has no net cost to GNP. This reflects partly the fact that in our base year domestic energy in the UK was exempt from VAT, so the carbon tax is actually serving up to a point to equalise tax rates across different commodities. Also, the carbon tax reduces energy imports, which, given the Armington trade assumptions in the model, this allows a rise in the real exchange rate, improving Britain's terms of trade by 0.45 per cent. As a result, much of the cost of the tax that one might expect to be borne in the UK is actually felt abroad (if 20 % of the UK's GNP is imported, the terms of trade gain to the UK would be 0.09 per cent of GNP). The effect on the rest of Europe and the World is a small reduction in real incomes.

Offsetting the terms of trade gain, real wages fall marginally, which deters labour, despite the cut in VAT. However, the reduced labour supply means that welfare in the UK including leisure is fractionally raised by the tax change.

Interestingly, carbon emissions outside the UK also fall slightly, so there is no 'leakage' problem for a carbon reduction policy in this model. This is partly the tax slightly reduces incomes abroad. Also, secondary energy (refined oil and electricity) export prices from the UK are raised by a carbon tax, which raises energy prices in the rest of Europe slightly.

In Column B the tax is introduced in Germany only. Since Germany, particularly the Eastern Laender, consumes a lot of highly polluting soft coal in its power generation sector, there is more scope than in the UK for low-cost fuel switching. As a result a similar tax rate produces slightly larger proportionate reductions in carbon emissions: nearly 20 ½ per cent. However, as this means the substitution of imported oil and gas for home-produced soft coal, the effect of the carbon tax on the terms of trade is actually slightly less than in the UK, with an improvement of 0.37 per cent. Also, since Germany already has substantial VAT on domestic fuel, the carbon tax does not offset an existing distortion there, and so the cost effects on GNP and welfare are rather higher than in the UK. GNP is reduced by 0.06 per cent, though since this is partly due to a drop in labour input due to lower real wages, the net effect on welfare including leisure is rather less than this.

A tax of 30 ECU in Germany produces slight increases in carbon emissions elsewhere, as production of energy-intensive industries shifts to the rest of the EU and to the Rest of the World (presumably Central and Eastern Europe).

Column C shows the effect of a 30 ECU tax in the EU excluding Germany and the UK. Because this is a heterogeneous grouping of countries, and oil or nuclear fuel inputs in one may not easily substitute for coal in another, the fuel substitution elasticities for the 'Other EU' countries have been reduced by 3/8 compared to the UK and Germany. The overall effect is for the 30 ECU/tC tax to reduce carbon emissions by 20 per cent: less than with a similar tax in Germany, but more than in the UK. The terms of trade effect, however, is greater (a rise of nearly 0.9 per cent), and this contributes to a rise in real wages, real GNP and welfare. The tax export effect means that incomes in the UK, Germany and the Rest of the World are reduced somewhat.

Column 4 shows the effects of a tax across the EU. The effect of the tax on emissions in the UK, Germany and rest of the EU is marginally greater than when the countries introduce the tax individually. The tax still has more effect proportionally in Germany, and less in the UK, than in the rest of the EU.

Since European countries trade with one another, the terms of trade gain to the countries introducing the tax is less than when they do so individually. Consequently, GNP in the UK and Germany falls slightly instead of rising, though that in the rest of the EU still rises a little. There is a significant export of the costs of the European tax to the rest of the World, where real GDP is reduced by 0.04 %.

Implications for other pollutants

Tables 4A and 4B show the implications of scenario 4 (the 30 ECU/tC tax across the EU 12) in 1995 for SO_2 and NOx emissions respectively. These assume no change in the application of abatement technology, so that the reduced fuel use and switch to cleaner oil and gas away from coal reduce SO_2 and NOx emissions. For SO_2 (Table 4A) the carbon tax has a large effect in Germany, where emissions are reduced by more than a third, due to the replacement of dirty brown coal use (particularly in the Eastern Laender) in power generation. Spain, Ireland, Denmark and the Netherlands, which all rely on dirty coal-fired generation also see large improvements. The effects are much less in the UK, where the main coal-fired power stations already had abatement technology fitted, and improvement is about 10 per cent, or Italy, where generation is largely oil-fired. The overall reduction in emissions in the EU 12 was 23 per cent, but half of European emissions in the base case come from outside the EU (particularly Poland and the Czech Republic) where the EU carbon tax has little effect on emissions.

NOx emissions (Table 4b) are more linked to oil consumption, especially in transport, and are less affected by a carbon tax. The reduction in the UK is just 4 per cent, while emissions in Germany are reduced by 7.86 per cent, and the other EU 12 (except Ireland and Luxembourg) see reductions in the range 4 to 10 ½ per cent.

Tables 5A and 5B from the deposition module of the RAINS model show that the benefit of lower sulphur emissions across the EU in terms of lower excess deposition (above the critical threshold where acid starts to build up) are concentrated largely in Germany, with Sweden and Poland also benefiting substantially, but much of the EU seeing much smaller effects. The reduction in excess deposition of nitrogen in acid rain is more evenly spread, with France the largest beneficiary, followed by the Scandinavian countries, Germany and Belgium.

As an alternative, countries might decide instead to maintain emission levels at the same level as without the carbon tax, spending less on abatement technology. This would produce an internal benefit to the country imposing the tax. In the case of the UK, RAINS suggests the saving in 1995 from lower costs of sulphur abatement (if the tax had been in place) would have been ECU 85 bn (1990 prices), or about 0.01 per cent of GDP. The UK saving on NOx abatement would have been just ECU 5 bn, though as the cost function for NOx abatement is highly nonlinear, in later years, when more abatement technology is expected to be applied, the marginal costs of abating NOx (and hence the value of reducing emissions by other means, such as a carbon tax) will be higher.

In Germany, the reduction in sulphur emissions in 1995 if the carbon tax had been imposed is greater than the total effects of technological abatement in place at that date.

4 Conclusions

This paper has shown how a static, multi-country CGE model can be used to analyse the economic effects of carbon abatement policy, taking account of international effects. It has also established a link with the RAINS model of acid rain depletion, which shows that there is a strong connection between carbon and sulphur emissions, and a weaker one with nitrogen emissions.

The model assesses a 30 ECU per tonne carbon tax. When this is applied across the 12 countries which were EU members in our base year (1992), the saving in carbon emissions is around 20 per cent compared with base: this is rather larger than the EU would need to achieve (compared with business as usual) in 2010, but such a saving might well be required in future commitments. Tax export effects, mean the cost of the carbon tax when applied across the EU is 0.12 % of GNP in the UK and 0.04 % in Germany, with a small gain in GNP in other EU countries, where the terms of trade benefit from taxing energy imports is greater. When countries such as the UK or Germany undertake a carbon tax on their own, the terms of trade benefit to them is greater than when EU members act in concert, and their GNP is barely affected by a tax of 30 ECU/tC.

Abatement of sulphur provides a further benefit of a carbon tax, as the encouragement to fuel saving and switching towards cleaner fuels means either lower emissions or alternatively, that countries need spend less on cleaning up technology. If emissions of sulphur fall, the main beneficiary would probably be Germany. In the event of countries instead choosing to keep emissions constant but spending less on abatement technology, the benefits would be more widespread. The UK would gain about an extra 0.01 % of GDP.

The effect on NOx emissions is a smaller reduction. The benefits of this are more widespread across the EU, but the reduction, at least in the early years, could be achieved at low cost by other means.

APPENDIX Table 1:

Elasticity assumptions

Production Function:

(i) Between imported intermediates from different countries: SIG4 = 2

(ii) Between imported and non-imported intermediates: SIG3 = 2

(iii) Between capital and labour: SIG2 = 0.8

(iv) Between fuels: SIGEN = 2 for UK or Germany. 1.25 for Other EU12 or ROW.

Except in power generation SIGEN = 4 for UK/Germany and 2.5 for Other EU12/ROW.

or in ag/comm (which includes transport) SIGEN = 0.8 for UK/Germany or 0.5 for Other EU12/ROW.

(V) Between non-fossil fuels: SIGNONF = 0.5

(vi) Top level between energy, non-energy and value added:

SIGMATOP = 0.5

Consumption Function:

(i) Between imports from different source countries: SIGMA3 = 2

(ii) Between composite imports and home-produced goods: SIGMA2 = 2

(iii) Between different consumption goods: SIGMA1 = 0.5

Labour Supply:

Uncompensated labour supply elasticity: ELLSUP = 0.15

Table 2: Energy Statistics from the database.

A: *Some key statistics of our database for the economies in the base year 1992* :

	GNP	Energy Consumption MTOE Final	Energy Consumption MTOE Primary	Carbon Dioxide MT Carbon
UK	0.91	144.5	192.4	160.0 (2.6%)
Germany	1.44	229.8	278.6	257.6 (4.1%)
Rest of EU 12	3.53	541.6	538.2	412.9 (6.6%)
Total EU	5.88	915.9	1009.2	830.5 (13.3%)
Rest of the World	17.00	4915.6	6341.0	5412.6 (86.7%)
Global total	22.88	5831.5	7350.2	6243.1 (100%)

B: *Energy price per unit carbon*

	(a) Expenditure by final energy users ECU mn	(b) M Tonnes Carbon emitted	(a)/(b) Final Expenditure per tC
UK	72204	160	451
Germany	123579	258	479
Rest of EU	333183	413	807
Total EU	528966	831	637
Rest of the World	1727291	5412	319
Global Total	2256257	6243	361

C: *Net energy export/imports*

	(a) Net exports MTOE	(b) Primary Consumption MTOE	(a)/(b) Net exports share
UK	-4.9	192.4	-2. 5 %
Germany	-186.7	278.6	-67. 0 %
Rest of EU	- 486.1	538.2	-90. 3 %
Total EU	- 677.7	1009.2	-67.2 %
Rest of the World	677.7	6741.0	+10.1 %

Table 3.
European Multi-country CGE model: Simulations of the effects of

a 30 ECU per tonne carbon tax compared to base.

30 ECU/tC tax applied in:

COUNTRY:		UK ONLY	GERMANY ONLY	OTHER EU 12	ALL EU
UNITED KINGDOM	CO_2 emissions	-17.15%	0.07%	0.18%	-17.54%
	primary energy cons	-15.52%	0.04%	0.37%	-15.55%
	real wage	-0.02%	-0.01%	-0.06%	-0.07%
	real GNP	0.00%	-0.01%	-0.04%	-0.04%
	welfare (eq varn)	0.01%	-0.01%	-0.03%	-0.04%
	terms of trade	100.45%	99.95%	99.82%	100.22%
GERMANY	CO_2 emissions	0.28%	-20.44%	-0.68%	-21.07%
	primary energy cons	0.45%	-16.33%	0.62%	-15.99%
	real wage	-0.01%	-0.17%	-0.04%	-0.22%
	real GNP	0.00%	-0.06%	-0.05%	-0.12%
	welfare (eq varn)	0.00%	-0.04%	-0.04%	-0.10%
	terms of trade	99.99%	100.37%	99.79%	100.10%
OTHER EU	CO_2 emissions	-0.67%	-0.09%	-20.10%	-20.23%
	primary energy cons	-0.23%	0.08%	-18.14%	-17.85%
	real wage	-0.02%	-0.01%	0.10%	0.11%
	real GNP	-0.01%	-0.02%	0.03%	0.02%
	welfare (eq varn)	-0.01%	-0.01%	0.03%	0.01%
	terms of trade	99.96%	99.90%	100.89%	100.74%
REST OF WORLD	CO_2 emissions	-0.03%	0.00%	-0.17%	-0.20%
	primary energy cons	-0.03%	0.00%	0.01%	0.00%
	real wage	-0.09%	0.00%	-0.06%	-0.06%
	real GNP	-0.05%	-0.01%	-0.03%	-0.04%
	welfare (eq varn)	-0.04%	0.00%	-0.02%	-0.03%
	terms of trade	99.90%	99.86%	99.32%	99.12%
CARBON EMISSIONS					
	Change MTC				
	UK	-27.44	0.11	0.28	-28.05
	Germany	0.72	-52.67	-1.76	-54.28
	Other EU	-2.75	-0.38	-82.98	-83.54
	Total EU	-29.47	-52.93	-84.46	-165.87
	Rest of World	-1.66	0.14	-9.11	-10.96
	Global	-31.14	-52.79	-93.58	-176.84
	Leakage(+)/extl savgs(-)	-3.70	-0.13	-10.59	-10.96

Table 4 A.
Sulphur emissions: change on 1995 base assuming EU 12 impose 30 ECU/t carbon tax.

Change in sulphur emissions based on 1995 energy use and second sulphur protocol controls

	Base kT	Change kT	Change per cent
REGION 1: UK	2395.4	-237.37	-9.91%
REGION 2: GERMANY	4705.62	-1580.1	-33.58%
REGION 3: OTHER EU12	6390.9	-1330.17	-20.81%
Italy	2089.12	-235.88	-11.29%
Spain	1838.06	-643.38	-35.00%
France	883.43	-122.17	-13.83%
Greece	426.95	-96.85	-22.68%
Belgium	344.56	-47.43	-13.77%
Netherlands	232.33	-61.39	-26.42%
Denmark	224.58	-66.22	-29.49%
Portugal	218.86	-21.12	-9.65%
Ireland	123.49	-35.73	-28.93%
Luxembourg	9.52	0	0.00%
TOTAL EU 12	13491.92	-3147.64	-23.33%
REGION 4: REST OF EUROPE	14054.93	17.5	0.12%
Poland	2572.35	6.51	0.25%
Russia	2341.69	-1.01	-0.04%
Ukraine	1711.35	-0.14	-0.01%
Czech	1428.67	3.26	0.23%
Bulgaria	1350.08	5.6	0.41%
Romania	922.05	2.48	0.27%
Hungary	804.52	0.94	0.12%
Others	2924.22	- 0.14	0.00%
SEAS	575.89	0	0.00%
TOTAL EUROPEAN EMISSIONS	28122.74	-3130.14	-11.13%

Table 4 B
NOx emissions: change on 1995 base assuming EU 12 impose 30 ECU/t carbon tax.

Change in NOX emissions based on 1995 energy use and current controls

	Base kT	*Change kT*	*Change per cent*
REGION 1: UK	1186.06	-48.13	-4.06%
REGION 2: GERMANY	1107.4	-87.09	-7.86%
REGION 3: OTHER EU12	3752.27	-240.02	-6.40%
Italy	1225.84	-58.46	-4.77%
Spain	768.75	-66.06	-8.59%
France	706.34	-28.37	-4.02%
Greece	265.72	-15.47	-5.82%
Belgium	190.12	-9.55	-5.02%
Netherlands	232.39	-19.4	-8.35%
Denmark	139.06	-14.52	-10.44%
Portugal	153.27	-16.08	-10.49%
Ireland	61.2	-12.05	-19.69%
Luxembourg	9.58	-0.06	-0.63%
TOTAL EU 12	6045.73	-375.24	-6.21%
REGION 4: REST OF EUROPE	6853.82	6.18	0.09%
Poland	675.66	1	0.15%
Russia	2328.27	2.08	0.09%
Ukraine	1256.49	1.47	0.12%
Czech	213.97	0.16	0.07%
Bulgaria	221	0.13	0.06%
Romania	422.86	0.5	0.12%
Hungary	163.13	0.07	0.04%
Others	1572.44	0.77	0.05%
SEAS	635.74	0	0.00%
TOTAL EUROPEAN EMISSIONS	13535.29	-369.06	-2.73%

Table 5a
RAINS model sulphur excess deposition (5% level) change from a 30 ECU carbon tax 1995

	Ecosystem area	*Excess deposition* No carbon *tax*	carbon *tax*	Change	Change *x area*
UK	7890	645.5	633.9	-11.6	91524
Germany	8693	1687.9	1341.2	-346.7	3013863.1
Belgium	621	1678.8	1441	-237.8	147673.8
Denmark	974	312	197.1	-114.9	111912.6
France	14483	118.4	88.9	-29.5	427248.5
Greece	2455	0	0	0	0
Ireland	489	32.6	30.5	-2.1	1026.9
Italy	6627	381.7	339.7	-42	278334
Luxembourg	88	1231.1	1053.9	-177.2	15593.6
Netherlands	320	1999.1	1699.4	-299.7	95904
Portugal	2829	0	0	0	0
Spain	8523	42.5	22.6	-19.9	169607.7
Austria	4872	1207.5	1081.6	-125.9	613384.8
Finland	32208	81.3	71.2	-10.1	325300.8
Sweden	43650	204.9	172.5	-32.4	1414260
Norway	32065	153.2	135.8	-17.4	557931
Switzerland	1189	810.4	701.8	-108.6	129125.4
Czech	2656	1966.8	1654.8	-312	828672
Estonia	1891	55.5	44.7	-10.8	20422.8
Hungary	1670	226.3	212.5	-13.8	23046
Poland	6372	1641.7	1392.1	-249.6	1590451.2
Slovenia	906	905	874.3	-30.7	27814.2

Table 5B
RAINS model nitrogen excess deposition (5% level) change from a 30 ECU carbon tax 1995

	Ecosystem area	Excess deposition No carbon tax	carbon tax	Change	Change x area
UK	7890	440.1	433.3	-6.8	53652
Germany	8693	819.3	801.5	-17.8	154735.4
Belgium	621	1082.1	1055.8	-26.3	16332.3
Denmark	974	315.5	196.4	-119.1	116003.4
France	14483	93.1	71.7	-21.4	309936.2
Greece	2455	0	0	0	0
Ireland	489	22.6	22.2	-0.4	195.6
Italy	6627	268	262.6	-5.4	35785.8
Luxembourg	88	750	732.5	-17.5	1540
Netherlands	320	1837.2	1813.8	-23.4	7488
Portugal	2829	0	0	0	0
Spain	8523	0.2	0.1	-0.1	852.3
Austria	4872	739.3	727.4	-11.9	57976.8
Finland	32208	67.5	60.5	-7	225456
Sweden	43650	171	165.3	-5.7	248805
Norway	32065	146.5	141.4	-5.1	163531.5
Switzerland	1189	806.9	783	-23.9	28417.1
Czech	2656	585	572.8	-12.2	32403.2
Estonia	1891	51	46.6	-4.4	8320.4
Hungary	1670	65.5	64.4	-1.1	1837
Poland	6372	689	676.7	-12.3	78375.6
Slovenia	906	436.9	428.3	-8.6	7791.6

Appendix: Equation Listing for CGE model GRANFA4.
26 Feb 1999.

LDEQUAZ: *Labour demand in value added for industry n in country I as a CES function of the wage relative to cost of value added*

$$L_{i,n} = \delta 2_{i,n} . VA_{i,n} . (PVA_{i,n} / W_i)^{\sigma 2_{in}}$$

KDEQUAZ: *Capital demand in value added as a CES function of the (fixed international) cost of capital relative to cost of value added*

$$K_{i,n} = (1 - \delta 2_{i,n}) . VA_{i,n} . (PVA_{i,n} / R)^{\sigma 2_{in}}$$

PVAEQUAZ: *Unit cost of value added calculated as total cost divided by value added.*

$$PVA_{i,n} = (L_{i,n} . W_i + K_{i,n} . R) / VA_{i,n}$$

VAEQUAZ: *Demand for value added related with a CES function to total demand for industry n in country i's output and the price of value added relative to average production cost*

$$VA_{i,n} = \alpha_{i,n} . YQ_{i,n} . (PG_{i,n} / PVA_{i,n})^{\sigma top_{in}}$$

CENEQUAZ: *Demand for energy products related with a CES function to total energy demand in the industry and the relative price of the fuel to aggregate energy.*

$$CIT_{i,n,en} = \delta en_{i,n,en}.VEN_{i,n.}\left(PEN_{i,n} / PCIT_{i,n,en}\right)^{\sigma en_{in}}$$

PENEQUAZ: *Average price of energy inputs to industry n in country I, calculated as average cost.*

$$PEN_{i,n} = \left(\sum_{e,n} CIT_{i,n,en}.PCIT_{i,n,en}\right) / VEN_{i,n}$$

VENEQUAZ: *Total energy input into industry n in country I, related by a CES function to the output price of n and the price of the aggregate energy input.*

$$VEN_{i,n} = \alpha en_{i,n}.YQ_{i,n}.\left(PG_{i,n} / PEN_{i,n}\right)^{\sigma top_{i,n}}$$

CMAEQUAZ: *Shares of each non-energy material in aggregate input of non-energy materials into industry n in country I, related by a CES function to aggregate non-energy material input and the price of the particular input relative to the aggregate input.*

$$CIT_{i,n,ma} = \delta ma_{i,n,ma}.VMA_{i,n}.\left(PMA_{i,n} / PCIT_{i,n,ma}\right)^{\sigma mat_{i,n}}$$

PMAEQUAZ: *Price or average cost of non-energy materials inputs into industry n in country i.*

$$PMA_{i,n} = \left(\sum_{ma} CIT_{i,n,ma}.PCIT_{i,n,ma}\right) / VMA_{i,n}$$

MAEQUAZ: *Demand by industry n in country I for aggregate non-energy materials, related by a CES function to total output of industry n in I and relative prices*

$$VMA_{i,n} = \alpha ma_{i,n.}YQ_{i,n}.\left(PG_{i,n} / PMA_{i,n}\right)^{\sigma top_{i,n}}$$

PGEQUAZ: *Average unit production cost of n in country I, calculated by average cost of inputs per unit output, less the URBT rebate (only for scenarios where carbon tax expenditure is rebated to the industry) and grossed up/down by the production tax/subsidy*

$$PG_{i,n} = \left(VA_{i,n}.PVA_{i,n} + VEN_{i,n}.PEN_{i,n} + VMA_{i,n}.PMA_{i,n} - VEN_{i,n}.URBT_{i,n}\right)\left(1 + TP_{i,n}\right) / YQ_{i,n}$$

CIX1EQUAZ: *Demand in country I for home-produced inputs of n by industry nn, related by a CES function to total inputs of n into nn and relative prices including specific tax.*

$$CIX1_{i,n,nn}.\mu H_{i,n,nn} = \alpha CIX_{i,n,nn,i}.CIT_{i,n,nn}$$
$$.\left(PCIT_{i,n,nn}.\mu H_{i,n,nn} / \left(PG_{i,nn} + SPTAX_{i,nn,i,n}\right)\right)^{\sigma 3_{i,n,nn}}$$

CIX1BEQUAZ: *Demand for composite imports of nn into industry n in country I as a CES function of total inputs of nn and relative prices.*

$$CIX1B_{i,n,nn}.\mu M_{i,n,nn} = \left(1 - \alpha CIX_{i,n,nn,i}\right)CIT_{in,nn}.\left(PCIT_{i,n,nn} / PCIX1B_{i,n,nn}\right)^{\sigma 3_{i,n,nn}}$$

PCITEQUAZ: *Price for composite imported inputs of nn into industry n in country I, calculated as an average price.*

$$PCIT_{i,n,nn} = \begin{pmatrix} CIX1_{i,n,nn}.\left(PG_{i,nn} + SPTAX_{i,nn,i,n}\right) \\ + CIX1B_{i,n,nn}.PCIX1B_{i,n,nn}.\mu M_{i,n,nn} \end{pmatrix} / CIT_{i,n,nn}$$

CIX2EQUAZ: *Demand for imported intermediate inputs of nn from country ii into industry n in country I, as a CES function of demand for the aggregate imported input of nn into n in country I and relative prices.*

$$CIX2_{i,n,nn,ii}.\mu_{ii,nn,i,n} = \alpha CIX2_{i,n,nn,ii}.CIX1B_{i,n,nn}.\mu M_{i,n,nn}$$
$$\times\left(PCIX1B_{i,n,nn}.\mu_{ii,nn,i,n} / \begin{pmatrix} PG_{ii,nn}.(1+TTARPB_{ii,nn,i,n}) \\ +SPTAX_{ii,nn,i,n} \end{pmatrix}\right)^{\sigma 4_{i,n,nn}}$$

PCIX1EQUAZ: *Price of the composite input of nn into industry n in country I, calculated by average cost.*

$$PCIX1B_{i,n,nn} = \left(\sum_{ii \neq i} CIX2_{i,n,nn,ii} . \begin{pmatrix} PG_{i,nn}.(1+TTARPB_{ii,nn,i,n}) \\ +SPTAX_{ii,nn,i,n} \end{pmatrix}\right) / \begin{pmatrix} CIX1B_{i,n,nn} \\ \times \mu M_{i,n,nn} \end{pmatrix}$$

* \\\\\\\\\\\\\\\\\\\\\\\\\\\\
* CONSUMER SIDE \
* \\\\\\\\\\\\\\\\\\\\\\\\\\\\

MDEF: *Full disposable income including net-of tax income from capital owned and valuation of the the full endowment of labour plus leisure, plus various transfers.*

$$INC_i = (R.KSB_i + W_i.EB_i).(1 - INCTAXR_i)$$
$$+ ALLOW_i.INCTAXR_i + TRANSFER_i.PUT2_i + \sum_{ii} GRANTRAN_{ii,i}$$

LLEQUAZ: *Demand for leisure time as a CES function of real full disposable income and the real wage net of tax.*

$$LEIS_i = \gamma L_{i.}(INC_i / PUT1_i).\langle PUT1_i \,|\, (W_{i.}(1 - INCTAXR_i))\rangle^{\delta i}$$

UT2EQUAZ: *Utility from consumption in i.*

$$UT2_i = (INC_i - LEIS_i.W_{i.}(1 - INCTAXR_i)) / PUT2_i$$

PUT1EQUAZ: *Cost of utility function including utility from leisure as a CES function of the net-of tax wage (= opportunity cost of leisure) and price index for the consumption bundle.*

$$PUT1_i = ((\gamma L_i.W_i.(1 - INCTAXR_i))^{(1-\delta_i)}$$
$$+ \gamma C_i.PUT2_i^{(1-\delta_i)})^{(1/(1-\delta_i))}$$

XD1EQUAZ: *Final consumer commodity demand for good nn in country I, as a CES function of total consumer expenditure and relative prices.*

$$XD1_{i,nn} = \gamma 1_{i,nn.}UT2_{i.}(PUT2_i / PXD1_{i,nn})^{\sigma 1_i}$$

PUT2EQUAZ: *Price of aggregate consumer bundle, calculated as average cost.*

$$PUT2i = \sum_{nn} XD1_{i,nn}.PXD1_{i,nn} / UT2_i$$

;

XD2EQUAZ: *Final consumer demand for home-produced good nn in country I, as a CES function of total final consumer demand for n in I and relative prices.*

$$XD2_{i,nn} = \gamma 2_{i,nn,i}.XD1_{i,nn}.\left\langle PXD1_{i,nn} \,\middle|\, \begin{pmatrix} SPCTAX_{i,i,nn} \\ +PG_{i,nn}.(1+TT_{i,nn}.TT1_i) \end{pmatrix}\right\rangle^{\sigma 2_{i,nn}}$$

XD2BEQUAZ: *Final consumer demand in country I for aggregate imported commodity nn, as a CES function of total final consumer demand for nn in I and relative prices.*

$$XD2B_{i,nn} = \gamma 2B_{i,nn,i}.XD1_{i,nn}.(PXD1_{i,nn} / PXD2B_{i,nn})^{\sigma 2_{i,nn}}$$

PXD1EQUAZ: *Price index for final consumer demand for nn in I, calculated as average cost.*

$$PXD1_{i,nn} = \begin{pmatrix} XD2_{i,nn}.\left(SPCTAX_{i,i,nn}+PG_{i,nn}.\left(1+TT_{i,nn}.TT1_i\right)\right) \\ +XD2B_{i,nn}.PXD2B_{i,nn} \end{pmatrix} / XD1_{i,nn}$$

XD3EQUAZ: *Final consumer demand for imports of nn from country ii into country I, as a CES function of aggregate imports of nn into I for final consumption and relative prices, including taxes.*

$$XD3_{i,nn,ii} = \gamma 3_{i,nn,ii}.XD2B_{i,nn}\left\langle PXD2B_{i,nn} / \begin{pmatrix} SPCTAX_{i,ii,nn}+PG_{ii,nn} \\ x\left(1+TT_{i,nn}.TT1_i\right).\left(1+TAR_{i,ii,nn}\right) \end{pmatrix} \right\rangle^{\sigma 3i_{,nn}}$$

PXD2BEQUAZ: *Price index for the final consumption of the aggregate import bundle, as average cost.*

$$PXD2B_{i,nn} = \left(\sum_{ii \neq i} \begin{pmatrix} XD3_{i,nn,ii}.SPCTAX_{i,ii,nn} \\ +PG_{ii,nn}.\left(1+TT_{i,nn}.TT1_i\right).\left(1+TAR_{i,ii,nn}\right) \end{pmatrix} \right) / XD2B_{i,nn}$$

* MARKET CLEARING EQUATIONS \ *

* \\\\\\\\\\\\\\\\\\\\\\\\\\\\

EXMKTG: *Market clearing in the goods market for good nn in country i.*

$$XD2_{i,nn} + \sum_{ii \neq i}\left(XD3_{ii,nn,i}\right) + \sum_{n}\sum_{ii \neq i}\left(CIX2_{ii,n,nn,i} + \sum_{nn} CIX1_{i,nn,nnn}\right) - YQ_{i,nn} = 0$$

GOVBUDGET: *Equation balancing the government budget. Income tax revenue plus import tariff revenue on consumer goods, plus VAT on imported consumer goods, plus VAT on home-produced consumer goods, plus specific taxes on imported inputs, plus specific taxes on home-produced inputs, plus tariffs on imported inputs, plus production taxes, minus various transfers equals zero (there is no direct government spending on goods and services in this model).*

$$\begin{aligned}
&INCTAXR_i.\left(R.KSB_i + W_i.\left(EB_i - LEIS_i\right) - ALLOW_i\right) \\
&+\sum_{nn}\sum_{ii \neq i}\left(XD3_{i,nn,ii}.PG_{ii,nn}.TAR_{i,ii,nn}\right) \\
&+\sum_{nn}\sum_{ii \neq i}\left(XD3_{i,nn,ii}.PG_{ii,nn}.\left(1+TAR_{i,ii,nn}\right).TT_{i,nn}.TT1_i\right) \\
&+\sum_{nn} XD2_{i,nn}.PG_{i,nn}.TT_{i,nn}.TT1_i \\
&+\sum_{nn}\left(XD2_{i,nn}.SPCTAX_{i,i,nn} + \sum_{ii \neq i} XD3_{i,nn,ii}.SPCTAX_{i,ii,nn}\right) \\
&+\sum_{n}\sum_{ii \neq i} CIX2i,n,nn,ii.SPTAXii,nn,i,n \\
&+\sum_{n}\sum_{nn} CIX1_{i,n,nn}.SPTAX_{i,nn,i,n} \\
&+\sum_{n}\sum_{nn}\sum_{ii \neq i} CIX2_{i,n,nn,ii}.PG_{ii,nn}.TTARPB_{ii,nn,i,n} \\
&+\sum_{n}\left(YQ_{i,n}.PG_{i,n}.TP_{i,n} / \left(1+TP_{i,n}\right)\right) \\
&-TRANSFER_i.PUT2_i - \sum_{ii} GRANTRAN_{i,ii} - \sum_{n} URBT_{i,n}.VEN_{i,n} = 0
\end{aligned}$$

EXMKTL: *Total labour employed equals labour endowment less leisure.*

$$\sum_{n}\left(LD_{i,n}\right)-\left(EB_{i}-LEIS_{i}\right)=0$$

Listing of Variables in the model:

Production Side:

$CIT_{i,n,en}$	Inputs of energy type en into industry n in country i.
$CIT_{i,n,ma}$	Inputs of non-energy material type ma into industry n in country i.
$CIX1_{i,n,nn}$	Input of home-produced nn into industry n in country i.
$CIX1B_{i,n,nn}$	Demand for composite imports of nn into n in country i.
$CIX2_{i,n,nn,ii}$	Input of nn from country ii into n in country i.
$K_{i,n}$	Capital employed in industry n in country i.
$L_{i,n}$	Labour employed in industry n in country i.
$PCIT_{i,n,en}$	Price of energy type en into industry n in country i.
$PCIT_{i,n,ma}$	Price of non-energy material type ma into n in country i.
$PCIX1B_{i,n,nn}$	Price of composite import of nn into n in country i.
$PEN_{i,n}$	Price of aggregate energy input into industry n in country i.
$PG_{i,n}$	Unit cost of output of industry n in country i.
$PMA_{i,n}$	Price of aggregate non-energy materials input into industry n in i.
$PVA_{i,n}$	Unit cost of value added of industry n in country i.
R	Unit cost of capital worldwide.
$VA_{i,n}$	Value added of industry n in country i.
$VEN_{i,n}$	Aggregate energy input into industry n in country i.
$VMA_{i,n}$	Aggregate input of non-energy materials into industry n in country i.
W_{i}	Wage in country i.
$YQ_{i,n}$	Gross output of industry n in country i.

Consumer Side.

INC_{i}	Full disposable income in country i.
$INCTAXR_{i}$	Income tax rate in country I (fixed for most scenarios).
$LEIS_{i}$	Time devoted to leisure rather than labour.
$PUT1_{i}$	Price index for utility (including leisure) in country i.
$PUT2_{i}$	Price index for aggregate consumption in country i.
$PXD1_{i,nn}$	Price index for consumption of nn in i.
$PXD2B_{i,nn}$	Price index for aggregate import bundle of nn for final consumers in i.
$TRANSFER_{i}$	Lump-sum transfer from government to consumers in country I (fixed for most scenarios.
$TT1_{i}$	Scalar to adjust all VAT rates in country i to give desired revenue.
$UT2_{i}$	Utility from consumption (excluding leisure) in country i.
$XD1_{i,nn}$	Final consumer demand for good nn in country i.
$XD2_{i,nn}$	Final consumer demand for home-produced good nn in country i.
$XD2B_{i,nn}$	Demand for aggregate bundle of imports of nn for final consumers in i.
$XD3_{i,nn,ii}$	Final consumer demand for nn from ii in i.

Listing of Parameters[3]

Production side:

$SPTAX_{ii,nn,i,n}$ Specific tax on inputs of nn from ii into production of n in i.
$TP_{i,n}$ Production tax on production of n in i.
$TTARPB_{ii,nn,i,n}$ Import tariff on inputs of nn from ii into n in i.
$URBT_{i,n}$ Rebate of carbon tax expenditure by industry n in I (for permit allocation study only).

$\alpha_{i,n}$ Share parameter for value added in total output.
$\alpha CIX_{i,n,nn,i}$ Share parameter for home-produced n in total inputs into n in i.
$\alpha CIX2_{i,n,nn,ii}$ Share parameter for imports of n from ii in total imported inputs into n in i.
$\alpha en_{i,n}$ Share parameter for energy in total inputs into n in i.
αma_{n} Share parameter for non-energy materials in total inputs into n in i.

$\delta 2_{i,n}$ Share parameter for labour in value added
$\delta en_{i,n,en}$ Share of fuel en in total energy use in industry n in i.

$\mu_{ii,n,nn,i}$ Initial ratio of price of nn from ii used by n in I including tax to pre-tax price.
$\mu H_{i,n,nn}$ Initial ratio of price of home-produced nn used by n in I including tax to pre-tax price.
$\mu M_{i,n,nn}$ Initial ratio of price of composite import of nn used by n in I including tax to pre-tax price.

$\sigma 2_{i,n}$ Elasticity of substitution between labour and capital.
$\sigma 3_{i,n,nn}$ Elasticity of substitution between home-produced and imported nn in inputs into n in country i.
$\sigma en_{i,n}$ Elasticity of substitution between fuels in production of n in i.
$\sigma mat_{i,n}$ Elasticity of substitution between non-energy materials in production.
$\sigma top_{i,n}$ Elasticity of substitution between value added, energy and materials.

Consumer Side.

$ALLOW_{i}$ Income tax allowance.
EB_{i} Labour endowment in country i.
$GRANTRAN_{i,ii}$ Lump-sum transfers of windfall profits to shareholders in ii due to grandfathering of permits in country i.
$SPCTAX_{i,ii,nn}$ Specific tax on consumption of nn from ii in country i.
$TAR_{i,ii,nn}$ Tariff on imports of nn from ii for final consumption in i.
$TT_{i,nn}$ Basic VAT rate (before adjustment to make government balance) on nn in i.

[3] In this type of modelling, a parameter is of fixed value, and does not vary endogenously as the model is solved, unlike a variable.

γC_i Share parameter for labour in labour endowment in country i.
γL_i Share parameter for leisure in labour endowment in country i.
$\gamma 1_{i,nn}$ Share parameter for good nn in final consumption in country i.
$\gamma 2_{i,nn,i}$ Share parameter for home-produced good nn in final consumption in country i.
$\gamma 2B_{i,nn,i}$ Share parameter for aggregate imported good nn in final consumption in country i.
$\gamma 3_{i,nn,i}$ Share parameter for imports of good nn from ii in aggregate imports of nn in country i.

δ_i Elasticity of substitution between labour and leisure in country i.
$\sigma 1_i$ Elasticity of substitution between different goods in final consumption in i.
$\sigma 2_{i,nn}$ Elasticity of substitution between home-produced and imported good in final consumption in i.
$\sigma 3_{i,nn}$ Elasticity of substitution between imports from different countries in final consumption of nn in i.

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