8

UNILATERAL TAXATION OF INTERNATIONAL ENVIRONMENTAL EXTERNALITIES AND SECTORAL EXEMPTIONS

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8.1 INTRODUCTION: UNILATERAL ABATEMENT, LEAKAGE AND EXEMPTIONS

In response to the greenhouse gas problem, the European Union decided in 1991 to stabilize its CO_2 emissions by the year 2000 at the level of 1990 (CEC, 1991). Subsequent efforts to introduce a joint European carbon tax have been abandoned, because other major economic actors such as Japan or the US refused to take similar steps (Rio, 1992) and the EU feared adverse impacts of unilateral action on the international competitiveness of its member countries. Recent negotiations on concerted global action have revealed serious problems in identifying concrete abatement targets and timetables for reducing global CO_2 emissions (Berlin, 1995). There is no consensus on 'quantified emission limitation and reduction objectives for specific time-frames' (so-called QELROS) as the issue of fair burden sharing remains unresolved. It is likely that any concrete steps towards emission abatement in the near future will take the form of unilateral actions, in which single countries will commit themselves to emission abatement policies. At the EU level, the EU Council of Environmental Ministers has left it to the member states to introduce carbon abatement measures on a national basis. Several northern member countries, where domestic voters stress the need for taking a leading role, have implemented some kind of carbon tax (OECD, 1995), in the hope that unilateral action will provide an incentive to other countries to join through an 'example or credibility effect'.

The problem with unilateral abatement of a global externality (such as carbon emissions) is that leakage can significantly decrease efficiency. Leakage occurs when emission reduction in the abating country is partially offset by increased emissions in non-abating countries through the relocation of emission-intensive industries, international energy market effects, exchange rate effects or changes in the levels of savings and investment (see Hoel, 1991; Rutherford, 1992; McKibbin and Wilcoxen, 1995; Rutherford, 1995). As the cost of unilateral action to combat global carbon emissions must be related to the net global emission changes (and not only to the domestic reduction), leakage increases the unilateral cost for meeting a given global reduction target. In extreme cases, leakage could even lead to a perverse outcome, such that a country acting unilaterally faces economic costs of abatement while global emissions are increased.[1] To avoid leakage and ensure the global efficiency of unilateral action, exemptions or tax-breaks for energy- and export-intensive industries are a commonly adopted strategy (CEC, 1992; TemaNord, 1994). However, an efficient exemption (tax-break) scheme requires careful accounting of the emissions embodied in imports and exports. Otherwise (consider, for example, the case of wide-ranging exemptions), carbon relocation due to unilateral action may be negligible but the cost of meeting a specific reduction target would increase significantly because the marginal cost of emission reduction would no longer be equalized across sectors. At the political level, the risks involved in costly exemptions are obvious when considering the lobbying power of energy- and export-intensive sectors such as the iron and steel industry or the chemical industry. Managers of these politically influential industries use the leakage argument to push forward wide-ranging exemptions.[2]

This chapter investigates the implications of sectoral exemptions from unilateral carbon taxes on leakage and abatement costs within the EU. The analysis is based on numerical computations with a large-scale general equilibrium model for the EU, which includes a detailed description of twenty-three production sectors and final demand in six major EU member countries. Our key finding is that leakage rates are not high enough to justify exemptions on global efficiency grounds. For a given domestic reduction target exemptions reduce leakage but induce significant excess costs when compared to uniform taxes. Not surprisingly, exemptions lower the adjustment costs for export- and carbon-intensive industries but this occurs at the expense of society as a whole. Our numerical results support the single-country analysis by Böhringer and Rutherford (1997) who identify the substantial excess costs of tax exemptions predicated on the assumption that leakage effects are of a second-order magnitude.

The remainder of this chapter is organized as follows: section 8.2 reviews important sources of leakage and discusses implications for the design of an analytical framework suited to the estimation of leakage rates. Section 8.3 presents policy scenarios for unilateral carbon abatement and reports numerical results. Section 8.4 summarizes and concludes.

8.2 LEAKAGE AND IMPLICATIONS FOR MODEL DESIGN

There are various channels through which carbon leakage can occur (for a summary, see Rutherford, 1995). Unilateral carbon taxes increase domestic fossil energy prices and cause the domestic carbon-intensive industries to relocate their activities abroad. A large region acting unilaterally cuts back fossil energy demands, which could induce a significant drop in world energy prices with a subsequent increase of demand in other regions. Other determinants of leakage include macro-economic effects operating through exchange rates, rates of return on investment and international capital flows.

It is hardly possible to account for all potential determinants of carbon leakage within a single analytical framework. A practical modelling approach is to focus on those determinants which are most important for the actual policy question. For the policy scenarios considered in this chapter (see section 8.3 below), we assume trade in carbon-intensive goods to be the key source of leakage and neglect energy market effects[3] as well as macro-economic effects. The scope for CO_2 leakage then crucially depends on the pattern of carbon intensity in the production of traded goods across different regions and the trade volumes of specific goods. This has at least three important implications for the design of the model used to analyse leakage effects. First, the regional disaggregation of the model should include all major trading partners of the unilaterally acting country. Second, the sectoral disaggregation of the model must cover those production sectors which exhibit significant total (i.e. direct and indirect) emissions as well as non-negligible trade volumes. And third, the choice of elasticities to indicate substitution possibilities across traded goods requires careful analysis in terms of empirical evidence.

These considerations have been incorporated in the development of a static multisector, multiregion general equilibrium model for the European Union, designed to investigate the implications of grandfathered permit systems on leakage and efficiency of unilateral carbon abatement within the EU (Böhringer *et al.*, 1997). The model includes a detailed description of twenty-three production sectors and final demand as well as bilateral trade, for six EU member countries which together account for the largest part of the overall EU trade volume, production output and carbon emissions: Germany, France, the United Kingdom, Spain, Italy and Denmark. We use this model to analyse the efficiency implications of sectoral exemptions. Table 8.1 provides an overview of the sectoral disaggregation which has been chosen on the basis of the sector-specific potential for carbon leakage exhibited in the benchmark production and trade pattern. The appendix provides a brief algebraic summary of the model's structure and the baseline parameterisation.

Table 8.1 Production sectors in the model

Sector	*Description**
COA	Coal, including 031 hard coal, 033 lignite, 050 coke
REF	Oil, including 071 crude oil and 073 refined petroleum products
GAS	Gas, including 075 natural gas and 098 manufactured gas
ELE	Electricity, including 097 electricity and 099 steam
ORE	135 Iron ore ECSC iron and steel products
NFM	137 Non-ferrous metals
CHM	170 Chemical products
CEM	151 Cement lime and plaster
CER	155 Earthenware and ceramic products
GLS	153 Glass
OMN	157 Other mineral and derived products
PLP	471 Pulp and paper and board
TRA	570 Wholesale and retail trade
CON	530 Building and civil engineering works
AGR	010 Agricultural, forestry, fishery
AIR	633 Air transport services
INL	617 Inland waterway services
ROD	613 Road transport
TRS	631 Maritime and coastal transport services
RLW	611 Railway transport services
MAN	Manufactured products aggregate, including 095 Water, 110 Nuclear fuels, 190 Metal products, 136 Non-ECSC iron and steel products, 210 Agricultural and industrial machinery, 230 Office machines, 250 Electrical goods, 270 Motor vehicles and engines, 290 Other transport equipment, 490 Rubber and plastic products, 473 Paper goods and products of printing, 410 Textiles and clothing, 430 Leather and footwear, 450 Timber and wooden furniture, 510 Other manufacturing products
FOO	Food products aggregate, including 310 Meat and meat products, 330 Milk and dairy products, 350 Other food products, 370 Beverages, 390 Tobacco products
SRV	Services aggregate, including 550 Recovery and repair services, 590 Lodging and catering services, 650 Auxiliary transport services, 670 Communications, 690 Credit and insurance, 710 Business services provided to enterprises, 730 Renting of immovable goods, 750 Market services of education and research, 770 Market services of health, 790 Other market services, 810 General public services, 850 Non-market services of education and research, 890 Non-market services of health, 930 Other non-market services

* Digits indicate R59 index of Eurostat classification.

8.3 SCENARIOS AND COMPUTATIONAL RESULTS

In our simulations we compare two different policy designs for CO_2 abatement in a single EU member country:

Uniform tax: The country acting unilaterally levies carbon taxes sufficient to reduce the domestic CO_2 emissions by 10%, 20% and 30% as compared to base year levels. The uniform carbon tax applies to all industrial sectors and final (household) demand.
Tax exemptions: The country acting unilaterally levies carbon taxes sufficient to reduce the domestic CO_2 emissions by 10%, 20% and 30%, but exempts selected export- and energy-intensive sectors from paying the tax.

The EU member country considered for unilateral action is Germany. This choice was made for two reasons: first, Germany is the main emitter of CO_2 within the EU and has a high level of intra-EU trade, such that leakage is potentially important.[4] Second, the advisory board of the German government suggested exemptions for energy- and export-intensive industries if Germany levied a unilateral carbon tax without similar steps being taken by other EU regions. Exemptions are discussed for sectors whose energy cost share of the gross production value is greater than 3.75% and whose export share of turnover is greater than 15% (Enquete, 1994). Based on these criteria the following five sectors are potentially exempted from carbon taxes: chemical products (CHM), earthenware and ceramic products (CER), glass (GLS), iron and steel (ORE) and pulp and paper (PLP). It should be noted that the share of exempted sectors in gross output and carbon emission is rather small.

Efficiency of abatement

Figure 8.1 illustrates the welfare cost[5] for a representative agent in Germany for reducing EU carbon emissions either by a unilateral uniform carbon tax or by a unilateral tax with exemptions.[6]

Our results suggest that exemptions significantly magnify the costs of EU-wide emission abatement, even when the exempted sectors have a small share in overall economic activity and carbon emissions. For a given domestic reduction target, exemptions decrease leakage (for the numerical results, see Table 8.2 below) but increase the costs of abatement: Exemptions for carbon-intensive industries impose a higher burden of cut-backs to non-exempted sectors, which typically exhibit lower, i.e. more expensive, carbon mitigation possibilities as compared to carbon-intensive sectors. The efficiency gains through reduced leakage are more than offset by efficiency losses through sub-optimal domestic carbon substitution. The excess cost of exemptions increase with the target level of emission reduction. Table 8.3 reports the marginal costs of abatement which reflect the higher infra-marginal cost of

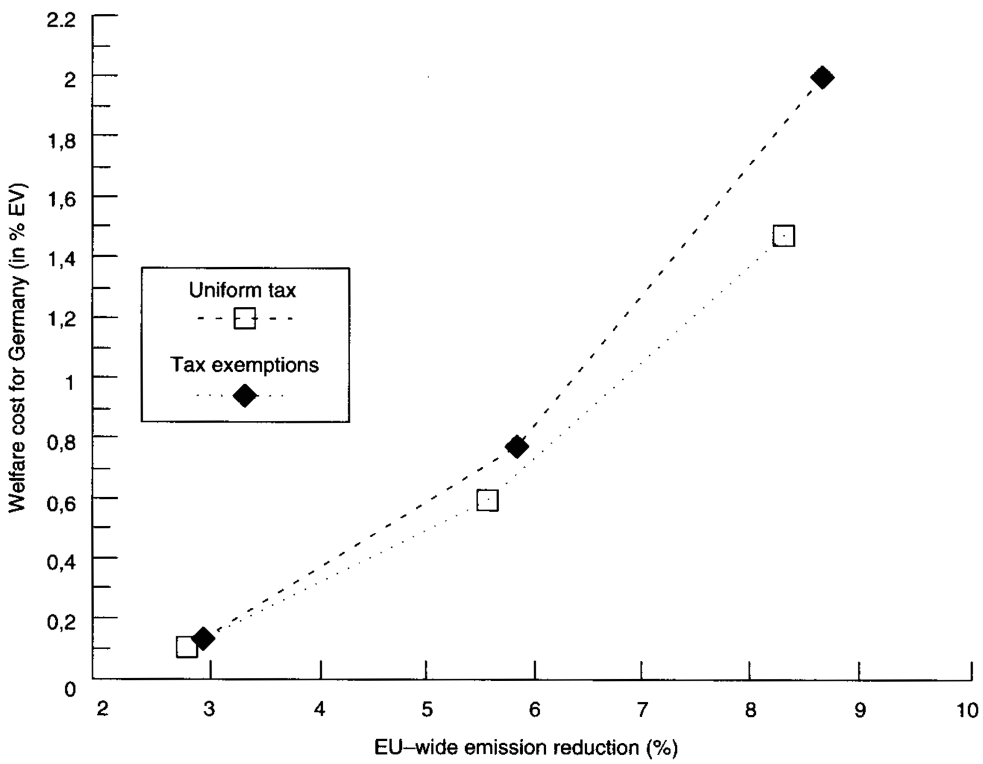

Figure 8.1 Welfare cost for Germany of reducing EU carbon emissions by unilateral action

Table 8.2 Leakage rates (%) due to unilateral abatement by Germany

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
France	2.9	3.1	3.1	0.6	0.7	0.9
Spain	0.5	0.5	0.6	0.3	0.3	0.4
Italy	1.4	1.5	1.6	0.5	0.6	0.7
UK	1.9	2.1	2.3	0.8	0.9	1.1
Denmark	0.1	0.1	0.1	0.2	0.2	0.2
EU total	6.8	7.3	7.7	2.4	2.7	3.3

Table 8.3 Marginal abatement costs: carbon taxes (in DM_{85} per ton CO_2)

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
Germany	43	105	196	75	190	367

exemptions as compared to uniform taxes. Exempting carbon-intensive sectors requires a higher carbon tax rate to meet a given domestic reduction target. Higher carbon tax rates indicate less potential for cheap carbon substitution possibilities and a stronger welfare-worsening resource reallocation (substitution) effect.

Sectoral effects: output, employment and exports

Tables 8.4–8.6 report the effects of both abatement policies on sectoral production, employment and export performance (note: sector ROI summarises all sectors except the exempted ones). We can see why managers and workers in carbon- and export-intensive industries would resist uniform taxes and lobby for tax exemptions. Uniform carbon taxes induce a severe decline in production, employment and exports in carbon- and export-intensive industries. Exemptions significantly lower the adjustment costs for these industries. However, the benefits for exempted sectors work at the expense of the non-exempted sectors (and of society as a whole: recall Figure 8.1).

Under uniform taxation, carbon- and export-intensive industries face a

Table 8.4 Output (% change from benchmark)

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
ORE	−26.7	−51.4	−71.7	−2.3	−5.9	−11.0
GLS	−2.8	−7.0	−13.3	−0.8	−1.9	−3.4
CER	−4.3	−10.2	−18.0	−1.0	−2.5	−4.5
CHM	−3.8	−9.3	−17.0	−0.7	−1.6	−3.1
PLP	−5.0	−11.7	−20.6	−3.9	−8.8	−15.1
ROI	−0.3	−0.7	−1.4	−0.8	−1.8	−3.3

Table 8.5 Exports (% change from benchmark)

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
ORE	−34.5	−61.0	−78.9	−3.0	−7.7	−14.2
GLS	−5.4	−13.2	−23.7	−1.3	−2.9	−4.6
CER	−4.9	−12.5	−23.3	−1.7	−4.1	−7.0
CHM	−4.9	−11.8	−21.2	−0.6	−1.4	−2.5
PLP	−7.5	−17.3	−29.3	−5.6	−12.5	−21.0
ROI	1.3	2.8	4.6	−0.7	1.4	−2.1

Table 8.6 Employment (% change from benchmark)

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
ORE	−25.37	−49.49	−69.91	−1.79	−4.74	−8.89
GLS	−1.91	−5.13	−10.21	−0.28	−0.64	−1.07
CER	−3.68	−8.74	−15.64	−0.53	−1.41	−2.65
CHM	−3.06	−7.69	−14.45	−0.23	−0.50	−1.02
PLP	−4.13	−10.01	−18.13	−3.43	−7.79	−13.25
ROI	0.39	0.86	1.39	0.07	0.15	0.27

sharp decline in sectoral production and exports because domestic carbon taxes increase the cost of carbon-intensive production and unilateral action implies a loss of comparative advantage. Due to the change in relative prices, domestic consumers substitute domestically produced carbon-intensive goods with carbon-extensive goods or cheaper imports; likewise, consumers from abroad reduce demands for relatively expensive carbon-intensive exports. Changes in sectoral employment involve the composition of output and substitution effects. The output effect on employment is generally negative (carbon taxes cause a reduction in output which decreases labour demand). The substitution effect of carbon taxes on employment is generally positive as carbon taxes reduce the marginal productivity of labour, i.e. the relative price for labour inputs. A positive substitution effect lowers the decrease in employment in the case of a negative output effect and strengthens the increase in employment in the case of a positive output effect. The larger the value share of labour, the larger the substitution effect and the more likely it becomes that carbon taxes will produce an increase rather than a decrease in sectoral employment. In our case, Tables 8.4 and 8.6 indicate that the negative output effect dominates the positive substitution effect for all sectors.

Tax incidence

In the present model we do not distinguish households with different factor endowments and different preferences. As a consequence, we cannot identify winners and losers in alternative abatement schemes at the household level. Nevertheless, Table 8.7 provides some insights into the effects of tax exemptions on factor earnings.

Carbon taxes decrease fossil energy demands in sectoral production and drive down the marginal productivity of labour and sector-specific capital, which implies a fall in the real wage and sector-specific rental rates. As expected, exemptions represent a windfall gain for stock holders in exempted sectors in comparison with the uniform tax case. These gains are at the

Table 8.7 Effect on specific factor earnings (% change from benchmark)

	Uniform tax			*Tax exemptions*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
Wage	−2.1	−4.8	−8.3	−2.7	−6.4	−11.3
Rents						
AGR	−1.6	−4.1	−7.9	−3.7	−9.1	−16.4
COA	−18.1	−33.0	−45.5	−16.3	−30.1	−42.9
REF	−5.4	−12.0	−19.9	−7.3	−16.0	−25.5
GAS	−22.0	−47.2	−72.7	−35.2	−70.1	−93.5
ELE	−2.4	−5.4	−9.2	−1.5	−4.0	−7.7
ORE	−26.7	−51.5	−72.0	−3.4	−8.5	−15.4
NFM	−4.0	−9.5	−16.8	−9.2	−20.3	−33.2
CEM	−2.9	−6.3	−10.4	−2.3	−5.5	−11.2
GLS	−3.7	−9.0	−16.4	−1.9	−4.6	−8.2
CER	−5.4	−12.4	−21.4	−2.2	−5.3	−9.6
OMN	−1.9	−4.5	−7.9	−2.3	−5.5	−9.9
CHM	−4.8	−11.4	−20.3	−1.9	−4.5	−8.1
PLP	−5.8	−13.6	−23.7	−5.0	−11.5	−19.5
CON	−0.9	−2.3	−4.1	−0.2	−1.0	−2.5
TRA	−1.1	−2.7	−5.0	−1.2	−3.2	−6.2
RLW	−3.5	−7.6	−12.3	−3.3	−7.6	−13.3
ROD	−2.1	−5.0	−8.8	−3.2	−7.6	13.3
INL	−6.1	−13.4	−22.2	−8.4	−18.8	−30.9
TRS	−1.9		−4.7		−8.0	

expense of capital owners in non-exempted industries as well as the representative worker who receives lower factor earnings due to higher marginal costs of abatement.

8.4 CONCLUSIONS

In this study, we have investigated the implications of sector-specific exemptions from unilateral carbon taxes on leakage and welfare costs. We find that tax exemptions for carbon- and export-intensive industries decrease leakage but increase the costs of EU-wide carbon abatement. Even though the share of exempted sectors in overall economic activity and carbon emission may be small, leakage rates are not high enough to justify exemptions on global efficiency grounds. At the sectoral level, exemptions significantly lower the adjustment cost for exempted sectors but these concessions are costly to society as a whole. Policy makers considering exemptions as a means of saving jobs in politically influential sectors should be aware that there might be more-efficient sectoral employment policies (see Böhringer and Rutherford, 1997).

The analysis presented here has neglected several issues which could be important for the robustness of our conclusions:

1 We adopted the Armington trade specification in which goods are differentiated by region of origin. It is well known that the magnitude of leakage and thus the justification for exemptions depends on the assumptions regarding the substitutability of traded (carbon-intensive) goods. In a world where traded goods are perfect substitutes (the Heckscher–Ohlin assumption) leakage rates tend to be very high, which justifies the special treatment of carbon- and export-intensive sectors on global efficiency grounds. Böhringer *et al.* (1997) illustrate this point in the context of grandfathered CO_2 permits. Empirical evidence on trade elasticities is ambiguous. Different assumptions on determinants such as the time-horizon (short-run versus long-run) or the level of aggregation seem to be the main reasons for diverging values or trade paradigms (Heckscher–Ohlin versus Armington). In this study, we followed the proposition of Armington and used uniform values of substitution elasticities for groups of traded goods across regions and sectors. To test the robustness of our results it would be useful to perform an extensive literature review and numerical sensitivity analysis on alternative empirical values for trade elasticities.
2 Leakage estimates depend crucially on the differences in the carbon/energy-intensities of sectors within and across regions. It is therefore important to employ good estimates on energy and emission flows associated with benchmark monetary flows, as provided by national input–output tables. The complementary use of physical flow data and economic input–output data reveals severe consistency problems and a thorough reconciliation of both data sources would be an important, yet very tedious task.
3 Our simplistic treatment of savings and investment is hardly suited to an investigation of the macroeconomic impacts of unilateral action on the level and location of investment (savings) as a further determinant of leakage.
4 The static model structure is less than perfectly suited to analysing the adjustment of physical and human capital stocks to carbon emission constraints. Another shortcoming in this context is the assumption of long-run perfect labour market mechanisms with flexible wages and frictionless labour movement between sectors within each region.

APPENDIX: ALGEBRAIC SUMMARY AND KEY ELASTICITIES

Summary of prices determining an equilibrium

P_{ir}	Output price of good i produced in region r
P^{M}_{ir}	Import price aggregate for good i imported to region r
P^{E}_{ir}	Composite price for aggregate energy inputs into sector i in regio r (i = C for final consumption)
P^{C}_{r}	Composite price for aggregate household demand in region r
P^{G}_{r}	Composite price for government demand in region r
P^{I}_{r}	Composite price for investment demand in region r
w_r	Economy-wide wage rate in region r
r_{jr}	Rate of return for sector-specific capital inputs, sector j in region
R	Rate of return for mobile capital (interregional and intersectoral)
PCO	Price of carbon emission rights

Summary of quantity indices determining an equilibrium

Y_{jr}	Level of production, sector j in region r
C_{R}	Aggregate household consumption, region r
I_r	Aggregate investment, region r

Key benchmark shares, endowment parameters and elasticities

$\theta^{M}_{i'jr}$	Benchmark value share of good i imports to sector j in region r
α^{E}_{jr}	Benchmark value share of energy inputs, sector j in region r
β^{E}_{jr}	Value shares for k = L (labour), S (sector-specific capital) and K (interregionally mobile capital) in sector j of region r
α^{KLE}_{jr}	Benchmark value share of capital, labour and energy composite, sector j of region r
α_{ijr}	Benchmark value share of non-energy input i in sector j of region r
$\theta^{MM}_{irr'}$	*Benchmark value share of region* r exports in aggregate imports of good i into region r'
ε_{ijr}	Carbon emission coefficient for energy input i into sector j in region r

α^{C}_{ir}	Benchmark value share of good *i* in aggregate non-energy household demand, region *r*
θ^{E}_{ijr}	Benchmark value share of energy good *i* in energy demand by sector *j* in region *r*
$\bar{L}_{r}$	Aggregate labour endowment for region *r*
$\bar{K}_{r}$	Aggregate endowment of interregionally mobile capital, region *r*
$\bar{K}^{S}_{jr}$	Sector-specific capital for sector *j* in region *r*
CRTS_{r}	Carbon emission rights endowment, region *r*
$\bar{G}_{r}$	Exogenously specified demand for public output, region *r*
$\bar{B}_{r}$	Benchmark balance of payment deficit/surplus
σ_{MM}	Elasticity of substitution between imports from different foreign countries
σ_{DM}	Elasticity of substitution between domestic and imported inputs or demands
σ_{E}	Elasticity of substitution between energy inputs

Exhaustion of product conditions

1 Production:

$$\Pi^{Y}_{jr} = P_{jr} - \sum_{i \notin EG} a_{ijr} \left(\theta^{M}_{ijr}\, \mathrm{P}^{M\ 1-\sigma_{DM}}_{ir} + (1-\theta^{M}_{ijr})\, \mathrm{P}^{1-\sigma_{DM}}_{ir}\right)^{\frac{1}{1-\sigma_{DM}}}$$

$$- a^{KLE}_{jr}\left[\alpha^{E}_{jr}\, \mathrm{P}^{E\ 1-\sigma_{KLE}}_{jr} + (1-\alpha^{E}_{jr})\left(w^{\beta^{L}}_{r}\, r^{\beta^{S}}_{jr}\, \mathrm{R}^{\beta^{K}}{}_{jr}\right)^{1-\sigma_{KLE}}\right]^{\frac{1}{1-\sigma_{KLE}}} = 0$$

2 Sector-specific energy demand:

$$\Pi^{E}_{jr} = P^{E}_{jr} - \left\{\sum_{i \in EG} \theta^{E}_{ijr}\left[\left(\theta^{M}_{ijr}\, \mathrm{P}^{M\ 1-\sigma_{DM}}_{ir} + (1-\theta^{M}_{ijr})\, \mathrm{P}^{1-\sigma_{DM}}_{ir}\right)^{\frac{1}{1-\sigma_{DM}}}\right.\right.$$

$$\left.\left. + \varepsilon_{ijr}\, \mathrm{PCO}\right]^{1-\sigma_{E}}\right\}^{\frac{1}{1-\sigma_{E}}} = 0$$

3 Import demand:

$$\Pi^{M}_{jr} = P^{M}_{jr} - \left(\sum_{r' \neq r} \theta^{MM}_{j'rr}\, \mathrm{P}^{1-\sigma}_{j'r\ \mathrm{MM}} + \theta^{MM}_{j\mathrm{ROW}r}\, \mathrm{P}^{M1-\sigma}_{j\mathrm{ROW}\,\mathrm{MM}}\right)^{\frac{1}{1-\sigma_{MM}}} = 0$$

4 Investment demand:

$$\Pi^{I}_{r} = \mathrm{P}^{I}_{r} - \sum_{i} a^{I}_{ir}\left(\theta^{M}_{iIr}\, \mathrm{P}^{M1-\sigma_{DM}}_{ir} + (1-\theta^{M}_{iIr})\, \mathrm{P}_{ir}{}^{1-\sigma_{DM}}\right)^{\frac{1}{1-\sigma_{DM}}} = 0$$

5 Public output:

$$\Pi_r^{G} = P_r^{G} - \prod_i \left(\theta_{iGr}^{M} P_{ir}^{M1-\sigma_{DM}} + (1 - \theta_{iGr}^{M}) P_{ir}^{1-\sigma_{DM}}\right)^{\frac{\alpha_{ir}^{G}}{1-\sigma_{DM}}} = 0$$

6 Household consumption demand:

$$\begin{aligned}&\Pi_r^{C} = P_r^{C} - \Big[\theta_{Cr}^{E} P_{Cr}^{E\;1-\sigma_{EC}} + (1 - \theta_{Cr}^{E})\\ &(\prod_{i \notin EG} (\theta_{iCr}^{M} P_{ir}^{M1-\sigma_{DM}} + (1 - \theta_{iCr}^{M}) P_{ir}^{1-\sigma_{DM}}) \frac{\alpha_{ir}^{C}}{1-\sigma_{DM}})^{1-\sigma_{EC}}\Big]^{\frac{1}{1-\sigma_{EC}}} = 0\end{aligned}$$

7 Household energy demand:

$$\begin{aligned}&\Pi_{Cr}^{E} = P_{Cr}^{E} - \Big[\sum_{i \in EG} \theta_{iCr}^{E} ((\theta_{iCr}^{M} P_{ir}^{M1-\sigma_{M}}\\ &+ (1 - \theta_{iCr}^{M}) P_{ir}^{\;1-\sigma_{M}})^{1-\sigma_{M}} + \varepsilon_{iCr} PCO)^{1-\sigma_{E}}\Big]^{\frac{1}{1-\sigma_{E}}} = 0\end{aligned}$$

Market clearance conditions

8 Labour:

$$\bar{L}_r = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^{Y}}{\partial w_r}$$

9 Sector-specific capital:

$$\sum_r \bar{K}_r = \sum_{j,r} Y_{jr} \frac{\partial \Pi_{jr}^{Y}}{\partial R}$$

10 Interregionally mobile capital:

$$\bar{K}_{jr}^{S} = Y_{jr} \frac{\partial \Pi_{jr}^{Y}}{\partial r_{jr}}$$

11 Output:

$$\begin{aligned}Y_{ir} = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^{Y}}{\partial P_{ir}} + C_{\mathrm{r}} \frac{\partial \Pi_r^{C}}{\partial P_{ir}} + I_{\mathrm{r}} \frac{\partial \Pi_r^{I}}{\partial P_{ir}}\\ + G_r \frac{\partial \Pi_r^{G}}{\partial P_{ir}} + \sum_{r'} M_{i'r} \frac{\partial \Pi_r^{M}}{\partial P_{ir}} + M_{ir\mathrm{ROW}}\end{aligned}$$

12 Imports:

$$M_{ir} = \sum_{j} Y_{jr} \frac{\partial \Pi^{Y}_{jr}}{\partial P^{M}_{ir}} + C_r \frac{\partial \Pi^{C}_{r}}{\partial P^{M}_{ir}} + I_r \frac{\partial \Pi^{I}_{r}}{\partial P^{M}_{ir}} + G_r \frac{\partial \Pi^{G}_{r}}{\partial P^{M}_{ir}}$$

13 Balance of payments:

$$\sum_{i,r} \bar{P}^{x}_{i} M_{irROW} = \sum_{i,r} \bar{P}^{M}_{i} M_{iROWr} + \sum_{r} \bar{B}_r$$

14 Supply-demand balance for carbon emission rights:

$$\sum_{r} CRTS_r = \sum_{j,r} Y_{jr} \frac{\partial \Pi^{Y}_{jr}}{\partial PCO}$$

Income and aggregate demand

15 Final consumption demand:

$$C_r = (1 - mps_r)(w_r \bar{L}_r + R\,\bar{K}_r + \sum_{j} r_{jr} K^{S}_{jr}$$

$$+ PCO\ CRTS_r - P^{G}_{r} \bar{G}_r - \bar{B}_r)/P^{C}_{r}$$

16 Savings:

$$I_r = mps_r\ (w_r \bar{L}_r + R\,\bar{K}_r + \sum_{j} r_{jr} K^{S}_{jr}$$

$$+ PCO\ CRTS_r - P^{G}_{r} \bar{G}_r - \bar{B}_r)/P^{C}_{r}$$

Index	*Description*	*Value*
σ_{KLEM}	Elasticity of substitution between the Leontief material input aggregate M and other inputs (capital K, labour L and energy E)	0
σ_{KLE}	Elasticity of substitution between energy inputs and value-added	0.5
σ_{KL}	Elasticity of substitution between labour, sector-specific capital and mobile capital	1
σ_{E_ELE}[a]	Elasticity of substitution between the aggregate of electricity and different fossil inputs in the energy aggregate of sectoral production and household demand	0.3
σ_{E_FOS}[a]	Elasticity of substitution between fossil energy inputs in the aggregate of fossil energy inputs at the level of sectoral production and household demand	0.5
σ_{NC}	Elasticity of substitution between different non-energy inputs into the non-energy bundle of household demand	1
σ_{DM}	Elasticity of substitution between domestic and imported inputs or demands in the Armington model	4
σ_{MM}	Elasticity of substitution between imports from different foreign countries in the Armington model	4
σ_{XROW}	Elasticity of export demand of ROW for imports from EU countries	4

Notes

[a] Instead of trading off different energy inputs in the energy aggregate of sectoral production and final demand with a uniform substitution elasticity of σ_E an additional nesting is introduced to account for differences of substitution between electricity inputs and non-electric (fossil) energy inputs.

NOTES

1 Assume, for example, that the energy efficiency level of the abating country is very high relative to other countries and unilateral action induces strong substitution of energy-intensive goods produced in the abating country through goods from abroad.

2 Obviously, they are less concerned with global efficiency but try to minimise adverse effects of carbon taxes on CO_2-intensive industries. Full exemptions to these industries could on balance even lower their production costs and provide a competitive edge over competing non-exempted industries.

3 The abstraction from energy market effects is a reasonable assumption for unilateral action of a single EU country because it has a relative small share in worldwide energy supply and demand.

4 At 1990 levels West Germany accounted for roughly 25% of the overall EU emissions (EU without East Germany); East Germany's emissions amounted to an additional 11% of the EU emissions (EU without East Germany).

5 Welfare costs are reported as Hicksian equivalent variations in income.

6 The empty squares and solid rhombs in Figure 8.1 indicate CO_2 emission abatement of Germany by 10%, 20% and 30% either by a uniform tax (squares) or by a tax with exemptions (rhombs).

REFERENCES

Böhringer, C. and Rutherford, T.F. (1997), 'Carbon taxes with exemptions in an open economy: a general equilibrium analysis of the German tax initiative', *Journal of Environmental and Economic Management*, 32(2): 189–203.

Böhringer, C., Ferris, M. and Rutherford, T.F. (1997), 'Alternative CO_2 abatement strategies for the European Union', in J. Braden and S. Proost, *Climate Change, Transport and Enviromental Policy – Empirical Applications in a Federal System*, Aldershot, Hants: Edward Elgar.

Commission of the European Communities (CEC) (1991), *A Community Strategy to Limit Carbon Dioxide Emissions and to Improve Energy Efficiency*, SEC(91), 1744 final, Brussels: CEC.

Commission of the European Communities (CEC) (1992), 'The climate challenge', *European Economy*, 51: 45–8.

Enquete (1994), 'Vorsorge zum Schutz der Erdatmosphaere' des Deutschen Bundestages, Arbeitspaper: Michaelis-Vorschlag-Steuerbefreiung von export- und energieintensiven Industrien, Bonn: Economica Verlag.

Hoel, M. (1991), 'Global environment problems: the effects of unilateral actions taken by one country', *Journal of Environmental Economics and Management*, 20(1): 55–70.

McKibbin, W. and Wilcoxen, P.J. (1995), 'Environmental policy and international trade', Department of Economics, University of Texas at Austin, mimeo.

Organization for Economic Cooperation and Development (OECD) (1995), *Environmental Taxes in OECD Countries*, Paris: OECD.

Rio (1992), *United Nations Earth Summit: Convention on Climate Change*, June, UN Conference on Environment and Development, Rio de Janeiro, Brazil.

Rutherford, T. (1992), 'The welfare effects of fossil carbon restrictions: results from a recursively dynamic trade model', in OECD, *The Costs of Cutting Carbon Emissions: Results from Global Models*, Paris: OECD, pp. 95–106.

Rutherford, T. (1995), 'Carbon dioxide emission restrictions in the global economy', Department of Economics, University of Colorado at Boulder, mimeo.

TemaNord (1994), *The Use of Economic Instruments in Nordic Environmental Policy*, Copenhagen: TemaNord.