2. Alternative CO_2 abatement strategies for the European Union

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Introduction

To combat global warming several international conferences (Toronto 1988, Cairo 1990, Rio 1992 and Berlin 1995) have called for significant reductions in world-wide carbon dioxide emissions associated with the combustion of fossil fuels. Because of the difficulties of identifying and implementing a 'fair' worldwide CO_2 reduction schedule for all countries, no concerted policy action has yet been undertaken. Given this situation, there is increasing political pressure for unilateral action within the European Union (EU): if any climate change policy is to be implemented, the developed countries will have to take a leading role. EU policy-makers, who fear negative impacts on international competitiveness, put EU-wide CO_2 reduction measures under the condition that other important developed economies (the US and Japan) take similar steps. This 'conditionality' clause has led groups in EU member countries to call for unilateral action at the national level in order to promote EU-wide or worldwide solutions. However, when one region or country acts unilaterally, significant efficiency losses potentially arise. 'Carbon leakage' occurs when emission reductions in one region are (partially) offset by increased emissions elsewhere. The question of how CO_2 reduction strategies within the EU or specific member countries can be implemented in order to minimize overall efficiency losses is linked to several important policy issues, such as:

- regional distribution of burdens and benefits;
- changes in comparative advantage (international competitiveness);
- distributional impacts and corresponding concessions to specific sectors (tax exemptions, grandfathered permits); and
- revenue recycling of carbon taxes and the possibility of a 'double dividend' when reducing pre-existing distortionary taxes.

Given the need for policy advice on the economic and emission implications of alternative CO_2 mitigation strategies, the main purpose of this chapter is to describe a general equilibrium model which can address important policy issues of CO_2 mitigation in a consistent, analytical way. The model presented incorporates a multisectoral and multiregional structure for the European Union and is based on the most recently available consistent data on bilateral trade and energy flows as well as national statistics on domestic production and consumption patterns. The potential usefulness of the model for policy advice is illustrated by simulations of several mitigation scenarios which are discussed among European policy-makers. The first set of scenarios examines the relationship between the scope of concerted action within the EU and the costs of meeting given reduction targets. The cases include (i) EU-wide abatement with tradable emission permits (uniform taxes); (ii) uniform reduction targets for all member countries without trade in national emission rights; and (iii) unilateral CO_2 taxes in one member country, Germany. The second set of scenarios considers the idea that freely distributing emission permits to industrial sectors on the basis of their benchmark emissions (that is, 'grandfathering') represents a cost-efficient CO_2 mitigation strategy which maintains international competitiveness of emission- and trade-intensive sectors and reduces carbon leakage, as has been argued by Koutstaal et al. (1994).

The results which emerge from the numerical computations are as follows:

- there are substantial efficiency gains within the EU associated with coordinated action: unilateral action by a single EU country is far more costly than EU-wide action to meet the same EU reduction target;
- accounting for general equilibrium effects and endogeneity of the permit price, there can be substantial efficiency costs associated with the grandfathering of emission permits as compared to auctioned permits;[1]
- grandfathering is justified on efficiency grounds only when leakage rates are substantial;
- it is difficult to estimate leakage rates associated with unilateral abatement by a single EU member state. The model-based result depends crucially on the formulation of international trade. In an Armington (regionally differentiated goods) model, leakage rates are low; in a Ricardo–Viner (homogeneous goods) model, leakage rates are high. At present, there is not sufficient empirical evidence to determine which of these models is closer to the truth;
- there are substantial differences in the distributional impacts of alternative CO_2 abatement strategies. The grandfathered permit approach is clearly beneficial to workers and capital owners in energy-intensive industries. Surprisingly, another finding is that the grandfathered permits are also beneficial to wage earners in a model with fully flexible wages. The efficiency costs of grandfathered permits work through reduction in the return to capital in other sectors.

Although the results confirm economic intuition, they are still quite preliminary. This chapter should be regarded as a progress report on ongoing research. Further sensitivity analysis on the underlying data and specific model features is required to test the robustness of concrete estimates of crucial values, such as the leakage rates associated with unilateral abatement policies.

The chapter is organized as follows. The first section motivates the choice of the scenarios by a short discussion of problems involved in the design of cost-efficient CO_2 abatement strategies. The second section provides an algebraic summary of the model structure. The third section summarizes the benchmark data sources and motivates the choice of regional and sectoral detail which is included in the empirical model. The fourth section describes the modelling experiments. The fifth section reports the numerical results and their economic interpretation. Finally, the conclusion entails a discussion of the findings.

Background: cost-efficient CO_2 reduction and unilateral action

As a main instrument of an international climate policy, some form of carbon tax has been proposed (Pearce 1991; Poterba 1991). Global cost-effectiveness suggests that a carbon tax should be uniform across countries and sectors in order to equalize the marginal cost of emission reduction across sources (Markusen 1975; Siebert et al. 1980). In spite of this proposition, no concerted action has yet been undertaken because the costs of uniform taxes may be inequitable and appropriate side-payments to make all signatory countries better off are very difficult to assess and negotiate (Burniaux et al. 1992). International CO_2 abatement could be characterized as a prisoners' dilemma where no country acting alone has an incentive to significantly cut its own emissions, given the negligible impact on the overall carbon concentrations in the atmosphere. The global nature of the CO_2 externality leads individual countries to insist on coordinated action (Commission of the European Communities 1992a).

Despite the impending economic losses, there might be reasons for single countries to take a leading role and to act unilaterally. For example, a country may decide to make short-term sacrifices in the expectation of long-run benefits from an increase in the number of signatory countries. Another motivation could be the domestic political environment where voters demand concrete environmental action.

Unilateral action to combat an international externality such as CO_2 emissions produces efficiency losses through spillover effects of carbon emission constraints on international markets. Unilateral CO_2 taxes affect international trade and the pattern of comparative advantage. One adverse consequence is that unilateral reductions may increase emissions by nonparticipating countries. This phenomenon has been referred to as carbon leakage. The problem of carbon leakage is likely to be significant for goods with a high energy content (Pezzey 1992; Rutherford 1993; Bohm 1993; Felder and Rutherford 1993). There are two basic channels through which carbon leakage can occur. First, leakage can arise when the production of CO_2-intensive goods relocates and increases the emission levels in the nonparticipating regions. Second, cutbacks of energy demands in a large region, because of CO_2 taxes, may induce a significant drop in world energy prices, which in turn could lead to an increase in demand in other regions. This again could offset part of the CO_2 reductions in the unilaterally acting region.

There are different strategies for regions acting unilaterally to avoid leakage and to increase efficiency of (global) CO_2 reduction. One approach would be to use direct trade restrictions by setting barriers to exports and imports of carbon(energy)-intensive products. In theory, this could produce a first-best optimal tax structure which involves a uniform carbon tax in concert with tariffs and subsidies on carbon embodied in imports and exports. If border adjustments through tariffs are ruled out because of trade agreements or GATT obligations, a second-best policy is to differentiate tax rates across domestic sectors (Hoel 1994). This theoretical proposition is reflected in the design of several unilateral mitigation strategies such as the EU proposal for an EU-wide combined energy and carbon tax (Commission of the European Communities 1992b) or the most recent CO_2 tax plan for Germany (Enquete-Kommission 1994), both of which exempt energy- and trade-intensive sectors from taxation. It is, however, unclear that the theoretical argument for tax differentiation justifies total exemptions. If leakage effects are of a second-order magnitude, wide-ranging exemptions will significantly increase the costs of stabilizing CO_2 emissions (Böhringer and Rutherford 1997). From a practical standpoint, there are reasons why an exemption system could be undesirable, for example high costs of administration and lobbying. Furthermore, the analytical derivation of optimal tax rates is already quite complex under very simplified assumptions (Hoel 1994). Even the definition of the 'optimal tax structure' is problematic in a world economy where trade taxes enacted for environmental objectives provide an opportunity for altering the terms of trade.

Grandfathered permits to production are an alternative remedy for adverse distributional impacts. Under arrangements such as the US SO_2 abatement programme under the 1990 Clean Air Act, emission permits are freely distributed to firms which subsequently can use the permits for their own emissions or sell the permits to others. Overall emissions may be reduced with the number of permits. In practice, grandfathered permits work as a subsidy which affects the allocation of resources. Carbon leakage provides one justification for assisting emission- and trade-intensive sectors through an appropriate design of the grandfathering system. In evaluating these programmes, it is important to evaluate the efficiency costs involved in this transfer of resources. Advocates claim that grandfathering can be used to ease the distributional effects of CO_2 mitigation on emission- and trade-intensive sectors 'without consequences for reaching the emission reduction goal and its cost efficiency' (Koutstaal et al. 1994, p. 1). Their argument is that grandfathered permits do not affect the input choice of a sector but leave the incentive to internalize the external effects of the CO_2 emissions. In this chapter it is argued that this logic overlooks potentially important general equilibrium effects. The excess burden of grandfathered permits as compared to auctioned permits depends on the initial distribution of permits and its subsequent reduction schedule. In the simulations below, it is shown that a 'popular' grandfathering system, where permits are allocated to industries on the basis of initial emission patterns with subsequent proportional cut-backs across sectors for given overall reduction targets can produce significant welfare costs which may not be outweighed by the decline in carbon leakage.

Model formulation

This section provides an algebraic summary of equilibrium conditions for a 'generic' static multiregional, multisectoral model in which:

1. output and factor prices are fully flexible and markets are perfectly competitive;
2. labour and capital are in fixed supply. Labour is intersectorally mobile within a region but cannot move between regions. Capital rents accrue to both sector-specific inputs and malleable capital. The latter is freely mobile across sectors and countries;
3. in international trade, goods are either differentiated by region of origin (the Armington model) or homogeneous (the Ricardo–Viner model). In the Armington model, regions are linked together through endogenous bilateral trade flows calibrated to base year values. In the Ricardo–Viner model, only base year net trade flows are replicated as goods move freely between countries. In both models, goods from countries which are not explicitly represented (rest of the world–ROW) are differentiated, and a set of export demand and import supply functions determine the trade between ROW and the countries whose production and consumption patterns are described in detail;[2]

4. government demand within each region as well as the balance of payment surplus are fixed at benchmark levels. Investment demand (savings) is determined through a constant marginal propensity to save by private households; and
5. there is one representative consumer for each region.

The model equations correspond to the three classes of conditions associated with an Arrow–Debreu general equilibrium: (i) exhaustion of product (zero-profit) conditions for constant-returns to scale producers; (ii) market clearance for all goods, factors, permits markets and trade balance with ROW; and (iii) income balance for representative agents in each of the explicitly modelled member states.[3] An equilibrium allocation determines market production, prices and incomes.

In the following algebraic exposition, the notation Π_{jr}^{X} is used to denote the profit function of sector j in region r; where X is the name assigned to this activity. Formally, all production sectors exhibit constant returns to scale, hence, differentiating Π_{jr}^{X} with respect to input and output prices provides compensated demand and supply coefficients which appear subsequently in market-clearance conditions.

Finally, it should be noted that the equations as presented in the following correspond to the Armington model with goods differentiated by region of origin. The Ricardo–Viner specification follows directly when P_{jr} is replaced by P_{X}, and the set of market-clearance conditions for good i in region r are replaced by a single equation for good i.

Exhaustion of product conditions

Within each region nested, separable, constant elasticity of substitution (CES) cost functions with three levels are employed to specify the substitution possibilities in domestic production between capital, labour, energy and material inputs (KLEM). The material input of good i in sector j corresponds to an Armington aggregate of non-energy inputs from domestic production and imported varieties which trade off with a constant elasticity of substitution (in equation (2.1) below, the index EG denotes the set of energy goods). At the top level, these material inputs are employed in fixed proportions with an aggregate of energy, capital (sectorally fixed and regionally mobile) and labour. A constant elasticity describes the substitution possibilities between the energy aggregate and the aggregate of labour and capital at the second level. Finally, at the third level capital and labour trade off with a unitary elasticity of substitution. On the output side good production is linked in fixed proportions (zero elasticity of transformation) to the entitlement of the producing sector with emission permits. This specification of the output side allows for transfer payments to be made to each sector reflecting 'grandfathering' of emission permits based on the benchmark emission patterns. The resulting zero-profit condition for the production of good j in region r is:

$$\Pi^{Y}_{jr} = P_{jr} + V_{jr} - \sum_{i \notin EG} a_{ijr} \left[\theta^{M}_{ijr} P^{M^{1-\sigma_{DM}}}_{ir} + (1-\theta^{M}_{ijr})\, P_{ir}^{1-\sigma_{DM}}\right]^{\frac{1}{1-\sigma_{DM}}}$$
$$-a^{KLE}_{jr}\left[\alpha^{E}_{jr} P^{E^{1-\alpha_{KLE}}}_{jr} + (1-\alpha^{E}_{jr})\left(W_{r}^{\beta^{L}_{jr}} r_{jr}^{\beta^{S}_{jr}} R^{\beta^{K}_{jr}}\right)^{1-\sigma KLE}\right]^{\frac{1}{1-\sigma KLE}} = 0 \qquad (2.1)$$

where:

P_{jr} is the output price of good j produced in region r,
V_{jr} is the value of emission permits per unit output of sector j in region r,
a_{ijr} is the benchmark value share of non-energy input i in sector j of region r,
θ^{M}_{ijr} is the import value share for sector i inputs to sector j in region r,
P^{M}_{ir} is the import price aggregate for good i imported to region r,
σ_{DM} is the elasticity of substitution between domestic and imported inputs or demands,
a^{KLE}_{jr} corresponds to the aggregate value share of capital, labour and energy inputs (*KLE* aggregate) in sector j of region r,
α^{E}_{jr} denotes the energy input value share of the *KLE* aggregate in sector j of region r,
P^{E}_{jr} stands for the composite price for aggregate energy inputs into sector j in region r,
σ_{KLE} represents the elasticity of substitution between the energy aggregate and the aggregate of capital and labour,
W_{r} is the economy-wide wage rate in region r,
r_{jr} is the rate of return for sector-specific capital inputs in sector j of region r,
R is the uniform rate of return for (interregionally and intersectorally) mobile capital,
β^{k}_{jr} denotes the value shares for labour ($k = L$), sector-specific capital (S) and interregionally mobile capital (K) in sector j of region r and
Y_{jr} is the associated dual variable which indicates the activity level of producing good j in region r.

Intermediate demands for fuels are split into energy throughput ('non-energetic') and energy use ('energetic') components. The first of these demands enters through the material aggregate, while the second forms the energy input aggregate. Energetic energy demands are specified by means of a two-level CES function. At the bottom level, an Armington aggregation function provides a constant elasticity of substitution between domestic and imported varieties of each energy good. The resulting Armington energy good is linked to a specific carbon emission coefficient which determines the carbon tax payment for this energy carrier. At the top level, different Armington energy goods (after accounting for carbon tax payments) trade off with a constant elasticity of substitution. The zero-profit condition for energy supply to sector *j* in region *r* is given by:

$$\Pi^E_{jr} = P^E_{jr} - \left[\sum_{i\in EG} \theta^E_{ijr} \left\{ \left[\theta^M_{ijr} P^{M^{1-\sigma_{DM}}}_{ir} + (1-\theta^M_{ijr}) P_{ir}^{1-\sigma_{DM}} \right]^{\frac{1}{1-\sigma_{DM}}} + \varepsilon_{ijr} PCO \right\}^{1-\sigma_E} \right]^{\frac{1}{1-\sigma_E}} = 0 \quad (2.2)$$

where:

- P^E_{jr} is the composite price for aggregate energy inputs into sector *j* in region *r*,
- θ^E_{ijr} is the benchmark value share of energy good *i* in aggregate energy demand by sector *j* of region *r*,
- σ_E is the elasticity of substitution between energy inputs,[4]
- ε_{ijr} is the carbon emission coefficient for energy input *i* in sector *j* of region *r*,
- PCO is the market price of carbon emission rights and
- E_{jr} is the associated activity level representing aggregate energy demand for producing good *j* in region *r*.

Import supply for region *r* and good *j* is composed of a CES aggregate of imports from all other regions (including ROW). The exhaustion of product condition for these import activities is given by:

$$\Pi^M_{jr} = P^M_{jr} - \left(\sum_{r'\neq r} \theta^{MM}_{jr'r} P_{jr'}^{1-\sigma_{MM}} + \theta^{MM}_{jROWr} P^{M^{1-\sigma_{MM}}}_{jROWr} \right)^{\frac{1}{1-\sigma_{MM}}} = 0 \quad (2.3)$$

where:

- $\theta^{MM}_{jr'r}$ is the benchmark value share of region r^1 exports in aggregate imports of good *i* into region *r*,
- θ^{MM}_{jROWr} is the benchmark value share of *ROW* exports in aggregate imports of good *i* into region *r*,
- σ_{MM} is the elasticity of substitution between imports from different foreign countries,
- P^M_{jROWr} is the price for good j produced in *ROW* and
- M_{jr} is the associated activity level of this constraint, meaning the level of demand in region *r* for the aggregate import variety of commodity *j*.

In each region composite investment is a Leontief aggregation of Armington inputs which are composed of domestic and imported commodities:

$$\Pi_r^I = P_r^I - \sum_i a_{ir}^I \left[\theta_{ilr}^M \, {P_{ir}^M}^{1-\sigma_{DM}} + (1-\theta_{ilr}^M)\, {P_{ir}}^{1-\sigma_{DM}}\right]^{\frac{1}{1-\sigma_{DM}}} = 0 \qquad (2.4)$$

where:

P_r^I stands for the composite price for investment demand in region r,
a_{ir}^I is the benchmark value share of input i in investment of region r,
θ_{ilr}^M denotes the import value share for sector i inputs into investment formation of region r and
I_r is the associated activity level, representing investment supply in region r.

Public goods and services are produced with a Cobb–Douglas aggregation of commodity inputs within which there is an Armington aggregate of domestic and imported commodities:

$$\Pi_r^G = P_r^G - \prod_i \left[\theta_{iGr}^M \, {P_{ir}^M}^{1-\sigma_{DM}} + (1-\theta_{iGr}^M)\, {P_{ir}}^{1-\sigma_{DM}}\right]^{\frac{\alpha_{ir}^G}{1-\sigma_{DM}}} = 0 \qquad (2.5)$$

where:

P_r^G is the composite price for government demand in region r,
θ_{iGr}^M denotes the import value share for sector i inputs into public good production of region r,
α_{ir}^G represents the value share of commodity i in public output of region r and
G_r is the level of public output in region r.

Household demand is given as a CES composite which combines consumption of an energy aggregate and a non-energy consumption bundle. Substitution patterns within the non-energy consumption bundle are Cobb–Douglas functions with an Armington aggregation of imports and domestic commodities. Non-energy Armington goods are an aggregate of domestic and imported varieties which trade off with a constant elasticity of substitution. Exhaustion of production for household demand is given by[5]:

$$\Pi_r^C = P_r^C - \left[\theta_{Cr}^E \, {P_{Cr}^E}^{1-\sigma_{EC}} + (1-\theta_{Cr}^E) \left\{ \prod_{i \notin EG} \left[\theta_{iCr}^M \, {P_{ir}^M}^{1-\sigma_{DM}} + (1-\theta_{iCr}^M) \, P_{ir}^{1-\sigma_{DM}} \right]^{\frac{\alpha_{ir}^C}{1-\sigma_{DM}}} \right\}^{1-\sigma_{EC}} \right]^{\frac{1}{1-\sigma_{EC}}} = 0 \quad (2.6)$$

where:

P_r^C stands for the composite price for aggregate household demand in region r,

θ_{Cr}^E represents the benchmark value share of the energy aggregate in household demand of region r,

P_{Cr}^E is the composite price for aggregate energy inputs into household demand in region r,

σ_{EC} is the elasticity of substitution between the energy aggregate and the non-energy consumption bundle in household demand,

θ_{iCr}^M denotes the import value share for sector i inputs into household demand of region r,

α_{ir}^C corresponds to the value share of non-energy commodity i in household demand for non-energy consumption bundle of region r and

C_r is the associated activity level representing aggregate household consumption in region r.

Energy consumption by households is characterized in the same way as energy demand of producing sectors, with zero-profit condition being expressed as:

$$\Pi_{Cr}^E = P_{Cr}^E - \left[\sum_{i \in E} \theta_{iCr}^E \left\{ \left[\theta_{iCr}^M \, {P_{ir}^M}^{1-\sigma_M} + (1-\theta_{iCr}^M) \, P_{ir}^{1-\sigma_M} \right]^{1-\sigma_M} + \varepsilon_{iCr} \, PCO \right\}^{1-\sigma_E} \right]^{\frac{1}{1-\sigma_E}} = 0 \quad (2.7)$$

where:

θ_{iCr}^E represents the benchmark value share of energy good i in aggregate energy demand by the household in region r,

ε_{iCr} corresponds to the carbon-emission coefficient for energy input i into household demand of region r[6] and

E_{Cr} is the associated activity level of household energy demand in region r.

Market clearance

In this exposition, Shepard's Lemma is used to provide a compact representation of compensated demand and supply functions. Primary factors of production are labour, sector-specific capital for each region and interregionally mobile capital. The market-clearance conditions for labour is expressed:

$$\overline{L}_r = \sum_j Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial w_r} \tag{2.8}$$

where:

$\overline{L}_r$ is the aggregate labour endowment for region r.

The supply–demand balance for inter regionally mobile capital is expressed:

$$\sum_r \overline{K}_r = \sum_{j,r} Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial R} \tag{2.9}$$

where:

$\overline{K}_r$ denotes the aggregate endowment of interregionally mobile capital for region r.

As to sector-specific capital, market clearance corresponds to:

$$\overline{K}^S_{jr} = Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial r_{jr}} \tag{2.10}$$

where:

$\overline{K}^S_{jr}$ is the sector-specific capital for sector j in region r.

Goods produced in each region enter intermediate demand, consumer demand, government and investment demand as well as import demand from other regions including ROW. The market-clearance condition for each produced commodity is expressed:

$$Y_{ir} = \sum_j Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial P_{ir}} + C_r \frac{\partial \Pi^C_r}{\partial P_{ir}} + I_r \frac{\partial \Pi^I_r}{\partial P_{ir}} + G_r \frac{\partial \Pi^G_r}{\partial P_{ir}}$$

$$+ \sum_{r'} M_{ir'} \frac{\partial \Pi^M_{ir}}{\partial P_{ir}} + M_{irROW} \tag{2.11}$$

where:

M_{irROW} is the aggregate export demand of ROW for good *i* from region *r* (see the foreign closure rule in equation (2.13) below).

The market for imports is analogous to the market for regional outputs. The supply–demand balance for imported goods is expressed:

$$M_{ir} = \sum_j Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial P^M_{ir}} + C_r \frac{\partial \Pi^C_r}{\partial P^M_{ir}} + I_r \frac{\partial \Pi^I_r}{\partial P^M_{ir}} + G_r \frac{\partial \Pi^G_r}{\partial P^M_{ir}} \tag{2.12}$$

As to the trade balance of regions with respect to the ROW, a simple foreign closure rule is employed. The Armington assumption of product heterogeneity is used along with a ROW export-demand function of constant price elasticity, price-taking behaviour of countries with respect to world import (ROW) prices (perfectly elastic foreign import-supply function), and an imposed balance of payment constraint to assure trade balance between single countries and ROW:

$$\sum_{i,r} \overline{P}^X_i M_{irROW} = \sum_{i,r} \overline{P}^M_i M_{iROWr} + \sum_r \overline{B}_r \tag{2.13}$$

where:
$\overline{B}_r$ is the net trade (balance of payment) surplus for region *r*,
$\overline{P}^M_i$ are the ROW prices of imports M_{iROWr} from ROW to regions *r* and
$\overline{P}^X_i$ are the ROW prices of exports M_{iROW} of region *r* to ROW.[7]

The supply-demand balance for carbon emission rights is expressed:

$$\sum_r CRTS_r = \sum_{j,r} Y_{jr} \frac{\partial \Pi^Y_{jr}}{\partial PCO} \tag{2.14}$$

where:

$CRTS_r$ gives the carbon-emission rights endowment of region *r*.

Income and aggregate demand

Total income of the representative household in each region is employed in fixed fractions on household demand and savings (constant marginal propensity to save). Given aggregate price indices for consumption and investment there is:

$$C_r = \frac{(1 - mps_r)\,(w_r \overline{L}_r + R\,\overline{K}_r + \sum_j r_{jr} \overline{K}^S_{jr} + PCO\,\theta^{CO}_{Hr}\,CRTS_r - P^G_r \overline{G}_r - \overline{B}_r)}{P^C_r} \tag{2.15}$$

$$I_r = \frac{mps_r\,(w_r\bar{L}_r + R\,\bar{K}_r + \sum_j r_{jr}\,\bar{K}^S_{jr} + PCO\,\theta^{CO}_{Hr}\,CRTS_r - P^G_r\,\bar{G}_r - \bar{B}_r)}{P^I_r} \tag{2.16}$$

where:

θ^{CO}_{Hr} is the fraction of carbon-emission permits allocated to households in region r and

mps_r is the constant marginal propensity to save in region r.

Grandfathered allowances which are produced at the same level of activity as regional outputs (see equation (2.1) above) render transfer payments to each sector which are equal to the allocated fraction of total revenues from carbon-emission permits:

$$V_{jr}\,Y_{jr} = PCO\,(1-\theta^{CO}_{Hr})\,CRTS_r\,\theta^{CO}_{jr} \tag{2.17}$$

where:

θ^{CO}_{jr} is the fraction of grandfathered permits allocated to sector j in region r.

Benchmark data and aggregation

As is customary in CGE modelling, the model is calibrated to available value shares and elasticity values. At the present state of model development, considerable work has been done to obtain percentage estimates for share parameters which provide a 'zeroth order approximation' of the underlying economy. The elasticity parameters used in the present version of the model are controversially discussed in economic literature, and the range of results presented below reflects this uncertainty (see, for example, the results emerging from different degrees of substitutability among traded goods).

The benchmark equilibrium data set for 1985 is constructed from three different sources which provide the most recent consistent data on energy and economic flows. These include the Eurostat input–output table with 59 production sectors for various EU member countries (Eurostat 1995); the CHELEM harmonized accounts on trade and world economy (WEFA 1995); and the International Energy Agency (IEA) energy balances (IEA 1994a).

Reconciliation of input–output data and trade data is the first step in constructing the base-year equilibrium. For this purpose, a nonlinear least squares procedure is employed to calibrate bilateral trade flows provided by CHELEM to the intra-EU and extra-EU trade totals provided in the Eurostat input-output tables. CHELEM does not cover all trade flows, and for the missing goods a target bilateral trade matrix representing the average overall traded goods is used.

The detailed description of production and consumption patterns within the EU includes six member countries which together account for more than 90 per cent of the overall EU trade volume and production output: Germany (DE), France (FR), United Kingdom (UK), Spain (ES), Italy (IT) and Denmark (DK).[8] All other countries are summarized to an aggregate rest of the world (ROW) whose representation is reduced to import and export flows to the EU countries.

The sectoral disaggregation is chosen on the basis of the potential for carbon leakage exhibited in the benchmark production and trade structure. The scope for CO_2 leakage crucially depends on the pattern of carbon intensity in the production of traded goods across different regions and the trade volumes of specific goods. To obtain the benchmark CO_2 emission intensities and intuition about the scope for leakage, a simple input-output calculation was performed. Let

- x_{ir} denote the total (direct and indirect) CO_2 emissions per unit production of good i in region r (in the exposition below, r and its alias s are used as the index for the six EU member countries explicitly included in the model),
- c_{ir} denote the direct CO_2 emission per unit production of good i in region r,
- A_{jsir} denote the input of good j from region s per unit production of good i in region r where A includes both domestic ($s=r$) and imported ($s \neq r$) goods and
- θ_{ir} denote the output value share of good i for region r in overall EU production.

The total CO_2 emissions per unit production of good i in region r are given by the following system of linear equations:

$$x_{ir} = c_{ir} + \sum_{j,s} A_{jsir}\, x_{js} \tag{2.18}$$

and, assuming an average emission intensity of ROW production:

$$x_{iROW} = \sum_{r} \theta_{ir}\, x_{ir} \tag{2.19}$$

As the total CO_2 emission of carbon per unit production x_{ir} crucially depends on the values of the direct CO_2 emissions c_{ir}, it is important to employ accurate estimates for these data. For this purpose the monetary flows of the national input–output tables are supplemented with physical flow data on the emission-relevant fossil fuel use in production sectors and final demand. The analysis of the implicit prices serves as a consistency check on the derived sector- and energy-specific CO_2 coefficients (in CO_2 units per national currency units). These reveal substantial price differences for the same fuel inputs across different sectors and countries.[9] The differences can be explained in part by price differentiation on energy markets (for example, cheap coal supply to electricity sector versus expensive coal supply to final demand) and by national regulation (for example, coal subsidies in Germany). In some cases, the implicit prices deviate significantly from official reports on market prices (for example, IEA statistics on energy prices and taxes, see IEA 1994b) without a satisfactory explanation, and these discrepancies call for further study. In short, the problem of reconciling physical energy flow data with economic input–output data is vexing yet widely ignored by economic model-builders working on carbon tax issues.

Despite the caveats on the concordance of energy and economic data, a key observation of the above input-output calculation is that carbon (emission) intensities vary considerably across the EU countries, which indicates a significant potential for leakage.[10] The variation of carbon intensities for traded goods across regions has important implications both for the design of instruments meant to reduce carbon leakage as well as for the appropriate level of sectoral disaggregation which has to be chosen in numerical simulations. For the calculations, the 59 sectors as given in the Eurostat input–output tables are ranked according to their scope of leakage and for the equilibrium model only those sectors are selected which reveal a significant potential for carbon leakage through trade in the benchmark production pattern. All other sectors are assigned to composite aggregates of food, manufacturing and services. This leads to a sectoral disaggregation with 23 sectors as given in Table 2.1.

Elasticities of substitution play an important role in equilibrium studies because they determine the sensitivity of economic aggregates to changes in policy instruments. In the case of carbon emission restrictions, lower elasticities are associated with higher carbon taxes (see Böhringer and Rutherford 1997). Welfare costs of CO_2 abatement depend on the input substitution possibilities in the production of energy- and carbon-intensive goods as well as the ease of substitution of these goods in intermediate demand and final consumption. Efficiency losses through carbon leakage are governed by the elasticity of substitution between the domestically produced good and the competing import aggregate, the latter of which is characterized through the substitution possibilities between imports from different foreign countries. In the Armington model, a common elasticity of substitution equal to four determines the

Table 2.1 Production sectors in the model

Sector	*R59 Index*	*Description*
COA	031, 033, 050	Coal (hard coal, lignite, coke)
REF	071, 073	Crude oil and refined petroleum products
GAS	075, 098	Natural gas and manufactured gases
ELE	097, 099	Electricity and 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 Electric 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 Nonmarket services of education and research, 890 non-market services of health, 930 Other nonmarket services

scope for substitution across domestic and imported varieties. In the Ricardo–Viner model, goods produced in different EU member states are perfect substitutes while imports from ROW remain differentiated with the Armington elasticity of substitution equal to four. Table 2.2 shows the assumptions on various key elasticities which are presently specified with common values across all regions. A major aspect of future research activities is to develop better estimates of these elasticities by sector and country.

Table 2.2 Key elasticities

Index	*Description*	*Value*
σ_{KLEM}	Elasticity of substitution between the Leontief material input aggregate and other inputs (capital, labour and energy)	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}*	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}*	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:* Instead of trading off different energy aggregates of sectoral production and final demand with a uniform substitution elasticity of σ_E as in equations (2.2) and (2.7) an additional nesting is introduced to account for differences of substitution between electricity inputs and non-electric (fossil) energy inputs (see note 2 for the nesting and the elasticity values employed)

Modelling experiments

In the simulations reported below, two sets of scenarios are distinguished which reflect different assumptions regarding the scope for unified policies within the EU and on the administrative framework for CO_2 abatement.

The first set of scenarios refers to an EU-wide CO_2 reduction strategy where all member countries undertake CO_2 mitigation measures. Four designs of an EU-wide abatement strategy which differ in the degree of emission trading and the consideration of grandfathered permits are considered:

(EU_1) *Auctioned permits tradable across EU countries.* The use of tradable emission permits of CO_2 equalizes marginal costs of abatement across member countries. The EU countries are initially endowed with emission rights equal to the benchmark emission level. Subsequent reduction in emission rights to meet exogenous reduction targets is proportional across countries.

(EU_2) *Grandfathered permits tradable across EU countries.* Permits are issued to production sectors on the basis of their benchmark emissions. Permit endowments are then proportionally reduced to meet reduction targets.

(EU_3) *Auctioned region-specific permits.* A uniform percentage reduction across member countries at the level of the overall EU reduction target without trade in national emission rights will typically lead to differences in the marginal cost of abatement.

(EU_4) *Grandfathered region-specific permits.* Each region faces the same proportional reduction in carbon emission. Permits are grandfathered proportional to benchmark emissions.

All of the EU abatement scenarios are computed in an Armington model in which goods are differentiated by country of origin.

The second set of scenarios considers unilateral CO_2 abatement by one EU member country, Germany.[11] No reduction measures are undertaken in the rest of the EU. The choice of Germany is motivated by the current discussion among German policy-makers on a unilateral CO_2 tax as the basic instrument to achieve national reduction targets.[12] Policy-makers of all German parties experience increasing public pressure in favour of a unilateral carbon tax which could be embedded in an overall tax reform.[13] On the other hand, German policy-makers fear the political consequences of severe employment cutbacks in carbon- and export-intensive industries (for example, iron/steel and chemical products), because of a loss of international competitiveness, and consider subsidies to these politically influential industries. The efficiency implications and the induced leakage rates of unilateral action are assessed for two different permit schemes and alternative specifications of international trade (Armington versus Ricardo-Viner).

(DE_1) *Auctioned permits for unilateral abatement, Armington model.* Germany unilaterally introduces emission permits. The resulting equilibrium is calculated in a model with goods differentiated by country of origin.

(DE_2) *Grandfathered permits for unilateral abatement, Armington model.* Germany unilaterally issues grandfathered emission permits allocated proportionally to base-year sectoral emissions. The equilibrium is calculated in a model with regionally-differentiated goods.

(DE_3) *Auctioned permits for unilateral abatement, Ricardo-Viner model.* Germany unilaterally introduces emission permits. The equilibrium is calculated in a model where goods produced in different EU countries are perfect substitutes.

(DE_4) *Grandfathered permits for unilateral abatement, Ricardo-Viner model.* Germany unilaterally adopts grandfathered emission permits allocated proportionally to base-year sectoral emissions. The equilibrium is calculated in a model where goods produced in different EU countries are perfect substitutes.

Table 2.3 summarizes the key characteristics of the scenarios.

Table 2.3 Overview of scenarios

Scenario	*Regional scope*	*Permit trade*	*Grandfathered permits*	*Economic model*
EU_1	All EU countries	Yes	No	Armington
EU_2	All EU countries	Yes	Yes	Armington
EU_3	All EU countries	No	No	Armington
EU_4	All EU countries	No	Yes	Armington
DE_1	Unilateral (only Germany)	n/a	No	Armington
DE_2	Unilateral (only Germany)	n/a	Yes	Armington
DE_3	Unilateral (only Germany)	n/a	No	Ricardo–Viner
DE_4	Unilateral (only Germany)	n/a	Yes	Ricardo–Viner

All of these scenarios are computed in a static framework with fixed labour and capital endowments. The revenues from auctioned permits are recycled lump-sum to the representative households in each region.[14] In the Armington model, 50 per cent of capital rents in the benchmark is assigned to sector-specific capital and 50 per cent accrues to interregionally mobile capital. In the Ricardo–Viner model all capital inputs are assumed to be sector specific (that is, there is no interregionally mobile capital in the Ricardo–Viner model).

In the counterfactuals, the number of emission permits is fixed to compute equilibria for target reductions of 10, 20 and 30 per cent. These reductions are applied either to the EU as a whole, if concerted EU-wide abatement is analysed, or to the benchmark emissions of Germany in unilateral abatement scenarios. Comparisons across scenarios provide a meaningful basis for welfare comparison. In any of the scenarios, permit prices may be interpreted as carbon tax levels which would produce an equivalent outcome.

Results

Results from the eight scenarios are summarized in Tables 2.4–8, which are presented at the end of this section. The numbers reported are current central estimates of the economic impacts of carbon-emission reduction policies within the EU. Table 2.4 reports the average cost of emission restrictions calculated as percentage Hicksian-equivalent variations in income.[15] Table 2.5 reports the marginal cost of emission restrictions which may be interpreted as the implicit carbon tax. Table 2.6 reports changes in emissions for different countries across different scenarios. Table 2.7 reports leakage rates and Table 2.8 reports sectoral labour adjustments for the unilateral abatement scenarios DE_1 and DE_2.

Consider first scenarios EU_1 and EU_3, that is EU abatement with and without trade in permits. Table 2.4 indicates that, from the standpoint of aggregate welfare, these scenarios are very similar. The EU countries gain relatively little in aggregate from permit trade when they are initially endowed with emission rights equal to the benchmark emission level and subsequent reduction in emission rights to meet exogenous reduction targets is proportional across countries. This finding is reflected in the comparability of permit prices across countries. The main outlier here is the UK which has substantially lower permit prices when acting alone. In Table 2.4 it is apparent that the UK stands to gain a significant amount from trade in emission permits, but the other countries are relatively indifferent.

The most dramatic result in Table 2.4 relates to the cost of grandfathering. Whether comparing EU_1 with EU_2, EU_3 with EU_4, DE_1 with DE_2 or DE_3 with DE_4, it is apparent that grandfathering introduces a significant efficiency cost. Turning to Table 2.5, it can be seen that the differences in average cost of abatement for these pairs of scenarios are reflected in substantial differences in the marginal cost of abatement. This indicates that there is an important interaction between the distribution of permit rents and the permit price itself. In simplistic terms, money from permit sales is returned to exactly those firms who are buying permits. The subsidies for the most polluting production sectors lead to lower relative prices for carbon-intensive goods and hence higher demands for these goods. This creates a higher demand for permits and a higher permit price.

The gross welfare cost of grandfathering is even higher in the case of unilateral action, where the measured equivalent income variation (EV) cost for Germany (DE) increases by a factor of two under grandfathered permits.

Comparing DE_1 with DE_3, it can be seen that the Armington model generally produces large welfare costs of emission restrictions. This is consistent with the logic presented earlier: the lower the elasticities, the higher the cost of achieving a given emission reduction. The Armington model, which is here specified with all trade elasticities equal to four, is considerably less flexible than the Ricardo–Viner model in which many trade elasticities are infinite.

The specific patterns of permit trade can be interpreted from Table 2.6. Here the specific evidence on permit trades which is suggested by the welfare results is reported. In EU_1, for a 20 per cent abatement target, the UK abates by 30 per cent and sells the excess abatement rights to France and Italy (primarily). Comparing EU_1 with EU_2, it can be seen that grandfathering of permits tends to reduce the level of permit trading by all market participants.

Considering the DE scenarios in Table 2.6, leakage effects in the Armington models (DE_1 and DE_2) are very small, but are enormous in the Ricardo-Viner model. Table 2.7 presents the calculated leakage rates. These are on the order of 70 per cent for a wide range of targets, which is about as large a rate as is reported in the literature. The rates should be regarded with some scepticism given that they emerge from a model in which many elasticities are not empirically estimated.

Comparing Tables 2.4 and 2.6, it is possible to see that unilateral action is far more costly than coordinated action. A 30 per cent unilateral abatement by Germany (DE_1) leads to 8 per cent EU-wide carbon reduction and involves much higher welfare costs than a coordinated EU-wide cut back of 10 per cent (EU_1): the total EU welfare cost for a 10 per cent abatement in scenario EU_1 is less than 0.1 per cent, whereas the total EU welfare cost associated with a 30 per cent unilateral reduction by Germany is 0.4 per cent. These are dramatic differences in the cost of abatement.

Turning finally to Table 2.8, it can be seen that even for the rigid Armington model, the application of a significant carbon tax creates enormous adjustment effects. For example, the level of adjustment for sector ORE (iron and steel) varies from 17 to 50 per cent for unilateral targets of 10 to 30 per cent.

Scenario DE_2 shows that the grandfathering of permits can have a big impact on leakage rates (Table 2.7) and employment effects (Table 2.8). Table 2.8 indicates that grandfathering permits can lead to a perverse result, in which employment in many of the emission-intensive sectors (such as ORE) actually increases rather than decreases as a result of carbon-emission restrictions.

To this point, the issue of how to quantify the costs and benefits of grandfathered permits has not yet been addressed. Grandfathered permits increase gross economic costs, but they simultaneously reduce leakage rates. In order to perform a meaningful comparison of costs and benefits, it is necessary to do a comparison *holding aggregate EU carbon emission constant.*[16] This calculation, which is based on economic costs for Germany (as reported in Table 2.4) and EU total emissions (as reported in Table 2.6), is presented in Figure 2.1 (see end of this section). The figure demonstrates that in terms of aggregate efficiency, the use of grandfathered permits is justified in the Ricardo–Viner model but unjustified in the Armington model. In other words, there is sufficient divergence in the leakage estimates for these two models to produce a qualitatively different assessment of the net benefit of the grandfathering permit system.

Throughout this discussion, Hicksian-equivalent variations of income have been used for a hypothetical representative agent as though it represented the interest of citizens in different countries. This masks potentially important differences across different households within these countries. In a more complete general equilibrium model, one based on detailed household surveys of consumption and factor income, it would be possible to sort out the winners and losers. Within the current modelling framework, the best that can be done is to look at the relative price of various production factors and assume that consumer preferences are identical. Proceeding in this manner, the welfare costs of various emission strategies for a representative employed worker in Germany have been evaluated by looking at how many goods can be purchased with a worker's salary (neglecting the costs inflicted on workers who must change jobs as a result of structural adjustment). The results are portrayed in Figure 2.2 (see end of this section). It could have been expected that grandfathered permits represent a windfall gain to capital owners in energy-intensive industries. It is therefore surprising to find that the grandfathering scheme is also preferred by the representative worker. Given that the net benefit (in the Armington model) is negative, it can be concluded that the efficiency costs of grandfathered permits work through reduction in the return to capital in other sectors.

Table 2.4 Welfare effects of carbon emission restrictions reported as Hicksian-equivalent variations in income (% change of benchmark)

Differentiated goods (Armington model)

	EU_1: Traded auctioned permits			*EU_2: Traded grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	–0.1	–0.6	–1.6	–0.1	–0.8	–2.3
FR		–0.3	–1.1	–0.1	–0.5	–1.6
ES		–0.3	–1.1	–0.1	–0.5	–1.7
IT		–0.4	–1.3	–0.1	–0.6	–1.9
UK	0.1		–0.2	–0.1	–0.5	–1.3
DK		–0.2	–0.9		–0.5	–1.8
EU total		–0.4	–1.2	–0.1	–0.6	–1.9

	EU_3: Auctioned permits			*EU_4: Grandfathered Permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	–0.1	–0.5	–1.6	–0.1	–0.8	–2.4
FR		–0.3	–1.0		–0.5	–1.6
ES		–0.2	–1.0	–0.1	–0.5	–1.8
IT		–0.3	–1.2		–0.6	–1.9
UK	–0.1	–0.6	–1.5	–0.2	–0.9	–2.4
DK		–0.3	–1.0	–0.5	–1.8	
EU total		–0.4	–1.3	–0.1	–0.6	–2.0

	DE_1: Auctioned permits			*DE_2: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE		–0.4	–1.2	–0.1	–0.8	–2.3
FR		–0.1	–0.1			
ES		–0.1	–0.1			
IT		–0.1	–0.1			
UK		–0.1	–0.1			–0.1
DK	–0.1	–0.1	–0.2			
EU total		–0.2	–0.4		–0.2	–0.7

Homogeneous goods (Ricardo–Viner model)

	DE_3: Auctioned permits			*DE_4: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE		–0.3	–0.8	–0.1	–0.7	–1.9
FR			0.1		0.1	0.1
ES			0.1			0.1
IT			0.1		0.1	0.1
UK			0.1		0.1	0.1
DK		0.1	0.2	0.1	0.1	0.2
EU total			–0.2		–0.2	–0.5

*Table 2.5 Carbon tax rates for different targets (DM/tonne CO_2)**

Differentiated goods (Armington model)						
	EU_1: Traded auctioned permits			*EU_2: Traded grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
EU	43	110	209	73	210	454
	EU_3: Auctioned permits			*EU_4: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	53	130	240	89	246	469
FR	58	156	318	87	250	469
ES	52	133	260	73	206	446
IT	68	181	358	94	277	469
UK	24	60	109	45	126	265
DK	36	97	189	66	209	469
	DE_1: Auctioned permits			*DE_2: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	51	125	234	90	252	490
Homogeneous goods (Ricardo–Viner model)						
	DE_3: Auctioned permits			*DE_4: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	25	63	123	78	213	444

*Notes:** For comparison: the combined energy/carbon tax as proposed by the EU involves an initial tax rate of 0.35 DM/GJ (energy tax) and 4.72 DM/tonne CO_2 (carbon tax) starting from 1996 with an annual nominal increase by 0.115 DM/GJ (energy tax) and 1.57 DM/tonne CO_2 (carbon tax) until 2020.

Table 2.6 Carbon emissions reductions by country (% of benchmark emissions)

Differentiated goods (Armington model)

	EU_1: Traded auctioned permits			*EU_2: Traded grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	–8	–18	–28	–9	–18	–29
FR	–8	–16	–24	–9	–18	–28
ES	–9	–18	–27	–10	–20	–30
IT	–7	–14	–22	–8	–17	–27
UK	–16	–30	–43	–13	–25	–35
DK	–11	–22	–32	–11	–20	–29
EU total	–10	–20	–30	–10	–20	–30
	DE_1: Auctioned permits			*DE_2: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	–10	–20	–30	–10	–20	–29
FR		1	1			
IT			1			
UK			1			
DK			1			
EU total	–3	–6	–8	–3	–6	–9

Homogeneous goods (Ricardo–Viner model)

	DE_3: Auctioned permits			*DE_4: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
DE	–10	–20	–30	–10	–20	–30
FR	8	15	18	1	2	4
ES	1	2	3		1	2
IT		1	3			1
UK	2	5	8	1	3	5
DK	2	7	14	1	2	4
EU total	–1	–2	–3	–2	–5	–7

Table 2.7 Leakage rates (%) associated with unilateral abatement by Germany

Differentiated goods (Armington model)

	DE_1: Traded auctioned permits			*DE_2: Traded grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
FR	2.1	2.2	2.3	0.4	0.5	0.7
ES	0.4	0.4	0.5			0.1
IT	1.1	1.2	1.3		0.1	0.3
UK	1.5	1.7	1.8	0.1	0.3	0.5
DK	0.2	0.2	0.3			0.1
Total	5.3	5.7	6.2	0.6	1.0	5.1

Homogeneous goods (Ricardo–Viner model)

	DE_3: Auctioned permits			*DE_4: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
FR	47.2	42.2	34.9	5.9	6.4	7.1
ES	2.2	2.6	3.0	1.4	1.6	1.8
IT	2.2	3.2	4.5	–0.2	0.5	1.2
UK	16.8	19.6	23.3	10.8	11.7	12.7
DK	2.2	3.0	4.3	0.8	1.0	1.3
Total	70.6	70.6	70.0	18.7	21.3	24.2

Table 2.8 Sectoral employment changes in Germany associated with unilateral abatement (in % change from benchmark)

Differentiated goods (Armington model)

*Production sectors**	*DE_1: Auctioned permits*			*DE_2: Grandfathered permits*		
	10%	*20%*	*30%*	*10%*	*20%*	*30%*
AGR	–1	–2	–4			
COA	–19	–33	–45	–15	–24	–29
REF	–4	–10	–16	–7	–15	–23
ELE	–1	–2	–4	7	16	25
ORE	–17	–34	–50	7	13	17
NFM	–2	–5	–9			
CEM	–1	–3	–4	7	15	22
GLS	–2	–4	–8	1	1	
CER	–3	–7	–12	1	1	
OMN		–1	–2	1	2	3
CHM	–3	–6	–11	1	1	1
PLP	–3	–7	–13	1	1	1
CON	1	2	4	1	3	5
TRA	1	1	2			
RLW	–2	–4	–6		–1	–2
ROD	–1	–2	–4	1	2	2
INL	–5	–12	–19	1	1	
TRS	–1	–3	–6			
AIR	–4	–10	–16	2	3	3

*Notes:** For key to prodution sectors, see Table 2.1, above.

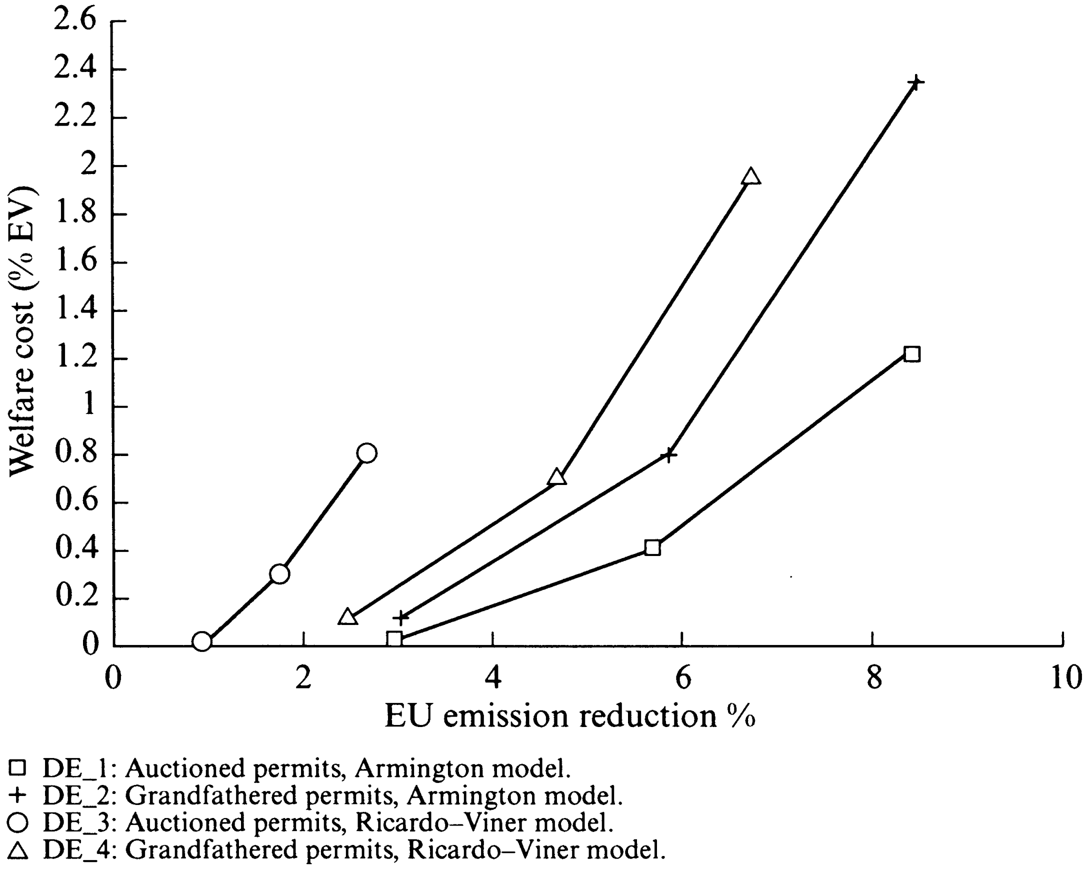
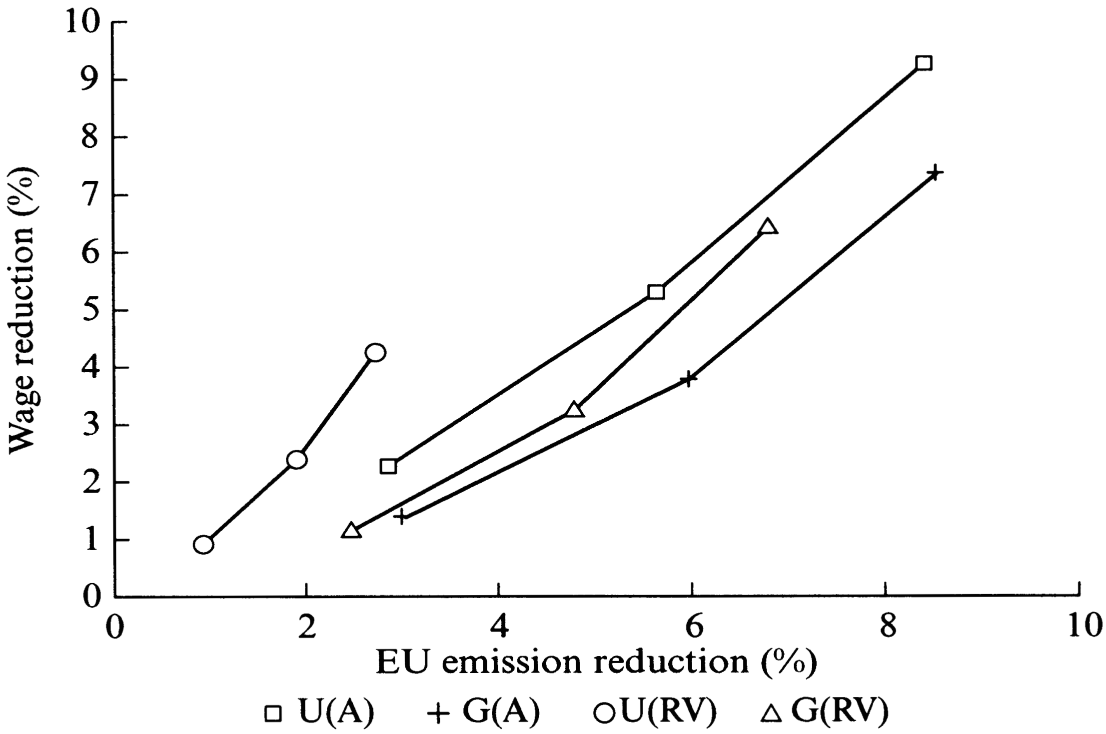


Figure 2.1 The welfare cost for a representative agent in Germany of alternative schemes for reducing EU carbon emission through unilateral action by Germany



Key
□ DE_1: Auctioned permits, Armington model.
+ DE_2: Grandfathered permits, Armington model.
○ DE_3: Auctioned permits, Ricardo–Viner model.
△ DE_4: Grandfathered permits, Ricardo–Viner model.

Figure 2.2 Welfare cost for a representative employed worker in Germany of alternative schemes for reducing EU carbon emission through unilateral action by Germany

Conclusion

This chapter has described the formulation, implementation and application of a multisectoral model for studying the effects of carbon-emission restrictions on trade and economic welfare within the European Community. The application has investigated the economic implications of coordinated and non-coordinated policies under auctioned as well as grandfathered permit systems.

The simulations provide three key insights. First, the scope for gains from permit trading within the EU is limited when EU countries are initially endowed with emission rights equal to the benchmark emission level and subsequent reduction in emission rights to meet exogenous reduction targets is proportional across countries. Carbon intensities of production computed using the Leontief inverse show some variation across countries, but no unexpected systematic differences appear.[17] The UK is an outlier in terms of carbon intensities and this difference shows up in the carbon trade scenarios. In an efficient (uniform permit price) equilibrium, the UK sells permits to the rest of the EU. Overall, this trade is relatively small and has insignificant welfare impacts. The implication of this result is that there would be relatively little efficiency loss if the EU were to contemplate emission reductions to a common abatement target across member states, provided that the member states act in unison.

The second finding is that coordinated action is essential if the EU is going to significantly reduce emissions. It is clear that when a country (here, Germany) acts unilaterally, carbon leakage can be a significant problem. The current model is unable to predict precisely how much leakage would result, but the simulations suggest that at a 20 per cent unilateral abatement by Germany, it would not be implausible that more than half of this reduction would be offset by increased emissions in other EU countries.

The final finding is that grandfathered emission permits are in most cases ill-advised. The model results indicate that these schemes can produce significant inefficiencies, either as part of an EU-wide agenda or within a unilateral abatement effort by Germany. In the Ricardo–Viner model of unilateral abatement, the use of grandfathered permits might be justified as a second-best measure to reduce leakage; but extremely high leakage rates are needed to offset the factor allocation losses induced by the implicit subsidies.

There are several issues absent from the present modelling framework which are potentially important:

- *Energy goods in the Armington model.* In the Armington model, all domestic, imported and exported varieties of every good are imperfect substitutes. This is clearly inappropriate for crude oil, coal and natural gas. At the present time, it is uncertain as to how many of the present results would carry over to a hybrid model in which some goods (oil, gas, coal, steel, aluminium and glass) are homogeneous while other goods remain imperfect substitutes.
- *Domestic energy policies.* Carbon taxes would apply amid a myriad of pre-existing domestic policies, including (but not limited to) strategic government protection of state energy sectors (for example, coal and electricity), and monopolistic competition in energy supply and distribution. Both government programmes and the realities of market structure have important implications for the effectiveness of carbon abatement policies, and these effects remain to be assessed.
- *Carbon taxes and sectoral adjustment.* In the policy debate, the application of carbon taxes is most often opposed on the basis of changes

in the pattern and level of employment. The present model adopts a flexible price formulation and frictionless labour movement between sectors within each region. It would be most interesting to examine the labour adjustment problem in a model incorporating endogenous unemployment. It is easy but unconvincing to include classical unemployment through downward rigidity of the real wage. A more intriguing approach would be to incorporate some representation of the demographic profile of workers by industry and country in order to develop an endogenous model of inter-sectoral migration with job-specific human capital. Another useful extension would be the incorporation of the role of unions which together with the employers bargain wages and employment (see, for example, Carraro and Galeotti 1994).

- *Environmental tax reform.* At present, the model entirely ignores public finance issues. It is relatively simple to incorporate taxes and public expenditure within the modelling format. The difficulty lies primarily in assembling plausible data to describe the various tax instruments.

In future research, these issues will be addressed using this model to the extent possible with available data.

Notes

1. In the auctioned permits system, the representative consumer (government) in one region is initially endowed with emission rights equal to the benchmark emission level. With grandfathered permit systems, permits are initially allocated to industries and households on the basis of specific distribution schemes (for example, distribution according to benchmark emission patterns).
2. The representation of ROW is reduced to import and export flows to these countries.
3. The model is formulated as a nonlinear system of roughly 1500 nonlinear inequalities using GAMS/MPSGE (Rutherford 1994) and solved using PATH (Dirkse and Ferris 1995).
4. Equation (2.2) as well as equation (2.7) below are minor simplifications. In the implemented model, one additional level of nesting for energy inputs is introduced, so that electric and non-electric energy first trade off (with an elasticity of 0.3), and subsequently fossil energy inputs (oil, gas and coal) enter in a lower CES nest with an elasticity of substitution equal to 0.5.
5. In a dual approach, utility-maximizing demand for consumption is represented as a cost (expenditure)-minimizing bundle of consumer goods which produces one unit of aggregate consumption utility.
6. As with industries, households have to buy emission rights (that is, pay taxes) in order to use carbon-emitting inputs within their energy consumption bundle.
7. The associated (dual) variable with this constraint indicates the real exchange rate relative to ROW (for example, 1985 ECU/1985 US$).
8. The choice of countries which are explicitly represented in the model has been made with respect to the availability of consistent data (here, Eurostat input–output tables for 1985) and the share of countries in overall EU trade volume and production output.
9. The prices for fossil fuels (oil, gas and coal) are inferred from the IEA data, based on a mapping from the IEA use sectors and the R59 branches of the Eurostat input-output tables to the following eleven sectors: AGR Agriculture, COA Coal, OIL, GAS Natural

and manufactured gases, ELE Electricity, ORE Iron and steel, CHE Chemical products, EIS Other energy-intensive sectors, EQU Equipment, CON Consumer goods, TRN Transport, SER Services including nonmarket services, and FCH Residential.

10. One example is electricity generation where France, because of the size share of nuclear and hydro power, emits a fraction of CO_2 per kWh compared to coal-based electricity production in Denmark or Germany. Given this heterogeneity among the large member states of the EU, one can only conjecture about the potential magnitude of cross country differences in production technique and the level of embodied carbon in energy-intensive goods.
11. The choice of Germany is motivated by two aspects. First, Germany is the biggest economy within the EU and has very high intra-EU trade flows in energy- and carbon-intensive commodities, suggesting significant scope for leakage. Second, the political situation in Germany is characterized by a high willingness to take a lead role in CO_2 reduction regardless as to whether other EU countries take similar steps.
12. As the main emitter of CO_2 within the EU, Germany continues to affirm its objective of reducing CO_2 emissions by 25–30 per cent by the year 2005, taking 1987 as the base year for the whole of Germany including the Five New *Länder*.
13. A popular argument for unilateral action is that CO_2 taxes used for the reduction of other distortionary taxes might allow for significant mitigation at net negative costs, that is, yield a so-called double dividend through an increase in traditional welfare and environmental quality (Greenpeace/DIW 1994, Gruppe Energie 2010, 1995). For an overview of the theoretical aspects related to the double dividend hypothesis, see Goulder (1994).
14. The current version of the model ignores other taxes in order to avoid extensive data collection and reconciliation on national tax systems. This simplification leaves doubts, however, regarding the possibility of positive or negative interactions of carbon taxes (carbon permits) with other market distortions.
15. For the accounting of carbon leakage in terms of aggregate efficiency, see the discussion of Figure 2.1, below.
16. Admittedly, it would be better to hold aggregate world emissions constant, but this is impossible within a 'subglobal' model. If it is assumed that EU, US and Japanese goods are relatively imperfect substitutes, the leakage effects outside of the EU from unilateral action by Germany may be neglected. Given the substantial share of the EU in German imports and exports, this is probably a reasonable assumption.
17. The scope for benefits of intra-EU trade of permits will change with alternative schemes for the initial distribution of permits and for the reduction patterns. Additional potential for increased benefits would also come from a wider range of variation in carbon intensities across countries with countries such as Portugal or Greece which are currently not incorporated.

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