Spillovers owing to carbon leakage

Kuik, O.J.

2005

Spillovers owing to carbon leakage

Onno Kuik

Report R05/02

March 8, 2005

This report was commissioned by: the Ministry of Housing, Spatial Planning and the Environment (VROM) of the Netherlands.

It was internally reviewed by: Prof.dr. Richard.S.J.Tol

IVM

Institute for Environmental Studies
Vrije Universiteit
De Boelelaan 1087
1081 HV Amsterdam
The Netherlands

Tel. ++31-20-5989 555
Fax. ++31-20-5989 553
E-mail: info@ivm.falw.vu.nl

Contents

Abstract

The term *carbon leakage* is used for the effect that a part of the CO_2 reduction that is achieved by countries that abate CO_2 emissions is offset by an increase in CO_2 emissions in non-abating countries. CO_2 reduction policies may increase the costs of producing CO_2-intensive goods and services, increase their price and reduce the rewards for factors and commodities intensive in their production. While these cost increases might stimulate innovation and technological change, they might also lead to changes in international patterns of trade and investment and might thus change the international pattern of CO_2 emissions: reducing them in abating countries and increasing them in non-abating countries.

The aim of this report is to provide a critical assessment of the available literature on carbon leakage, both conceptual and quantitative. After a brief introduction to the concept of carbon leakage, this reports discusses the mechanisms (or “channels”) through which it can occur. Subsequently, it presents and discusses a number of estimates of the potential size of leakage.

Finally, the report considers some implications for the post-Kyoto agenda on climate policies. In general, it concludes that while a certain amount of leakage may be unavoidable in the short to medium term, in the long run sustainable innovation in the energy system, competitiveness and leakage reduction should go hand in hand.

Acknowledgements

The present report is part of a research project called ‘Carbon leakages and induced technological change: the negative and positive spillover impacts of stringent climate change policy’ (or, more briefly, the so-called ‘Spillovers of climate policy’ project). This project is financed by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) as part of its National Research Programme on Climate Change (NRP-CC), particularly its sub-programme dealing with ‘scientific assessments and policy analyses’. This programme is implemented by the National Institute of Public Health and the Environment (RIVM).

The project ‘spillovers of climate policy’ has been coordinated by the unit Policy Studies of the Energy Research Centre of the Netherlands (ECN), where it has been registered under no. 77599. Together with the present report, companion reports are published as part of the project by Sijm (2004b), Annevelink et al. (2004), Lako (2004) and Oikonomou et al. (2004). The author would like to thank the following persons for their comments on earlier drafts of this report: Reyer Gerlagh (IVM), Jip Lenstra (VROM), Tom Manders (CPB), Sergey Paltsev (MIT), Tom Verbeke (Ghent University), Harmen Verbruggen (VU, Economic Faculty), Richard Tol (IVM, Hamburg University, and Carnegie Mellon University) and his team members of the Spillovers project. But the author remains of course responsible for any mistakes in the current version of the report. Previous versions of the report were presented in The Hague, The Netherlands (July 2nd , 2004) and Buenos Aires, Argentina (December 7th , 2004).

Additional information on this report can be obtained from Onno Kuik (e-mail: onno.kuik@ivm.falw.vu.nl, or telephone: +31 20 598 9513).

Summary for policy makers

The term *carbon leakage* is used for the effect that a part of the CO_2 reduction that is achieved by countries that abate CO_2 emissions is offset by an increase in CO_2 emissions in non-abating countries. CO_2 reduction policies may increase the costs of producing CO_2-intensive goods and services, increase their price and reduce the rewards for factors and commodities intensive in their production. While these cost increases might stimulate innovation and technological change (Sijm, 2004b), they might also lead to changes in international patterns of trade and investment and might thus change the international pattern of CO_2 emissions: reducing them in abating countries and increasing them in non-abating countries.

The size of carbon leakage because of the implementation of the Kyoto Protocol is still uncertain: it is estimated that between 5 and 20 percent of CO_2 mitigation in Annex I countries will be offset by increases in emissions by non-Annex I countries. Some observers expect a lower rate of leakage because they expect that governments of Annex I countries will take active measures to prevent industrial relocation. A higher rate of leakage may, however, be caused by the non-participation of major Annex I countries such as the U.S. and Australia and non-binding targets for Eastern Europe and the former Soviet Union.

In the literature, a number of distinct mechanisms or “channels” of carbon leakage have been identified. The most important channels can be grouped under the following four headings: i) international trade in energy goods, ii) international trade in other goods and services, iii) international trade in factors of production, and iv) international interaction among government policies. There seems to be some consensus among researchers that while changes in the international markets of *energy goods* is the dominant source of carbon leakage in the short to medium term, the relocation of international investment and industrial relocation may well become the dominant source of carbon leakage in the more distant future.

Carbon leakage reduces the global cost-effectiveness of domestic and EU CO_2 mitigation measures. The first-best policy to counteract leakage is increasing country participation in international greenhouse gas mitigation agreements. The second-best policy is applying trade measures to the import and export of CO_2-intensive manufactures in the international trade with non-participants to the above agreements. The third-best policy is to design and implementation of domestic or European emission reduction schemes that combine an effective ‘abatement effect’ with a weak ‘output-substitution’ effect for ‘exposed’ sectors. International emissions trading is a valuable option in this respect.

An alternative option would be to accept a certain ‘unavoidable’ rate of leakage in the short to medium term (which is believed to be primarily caused by relative changes in the prices of energy goods) and concentrate on action to avoid leakage through industrial relocation in the long run. In the long run, sustainable innovation in the energy system, competitiveness and leakage reduction should go hand in hand.

1. Introduction

The term *carbon leakage* is used for the effect that a part of the CO_2 reduction that is achieved by countries that abate CO_2 emissions is offset by an increase in CO_2 emissions in non-abating countries. CO_2 reduction policies may increase the costs of producing CO_2-intensive goods and services, increase their price and reduce the rewards for factors and commodities intensive in their production. While these cost increases might stimulate innovation and technological change, they might also lead to changes in international patterns of trade and investment and might thus change the international pattern of CO_2 emissions: reducing them in abating countries and increasing them in non-abating countries. Model predictions of the rates of carbon leakage due to the implementation of the Kyoto Protocol range from very small to very large.

This report presents a structured assessment of the academic literature on carbon leakage and formulates its potential implications for policy. The structure of the report is as follows. Chapter 2 introduces the concept of carbon leakage and explains why carbon leakage can be characterized as an international 'distortion'. Chapter 3 identifies different 'channels' of carbon leakage and discusses the main findings in the literature on each of these channels. Chapter 4 presents a brief overview of the modeling approaches towards the estimation of the size of carbon leakage in specific policy scenarios. Chapter 4 also presents some estimates of the size of carbon leakage and discusses their validity and limitations Chapter 5 presents some ideas on the policy implication of carbon leakage in international climate change policies, while Chapter 6 offers overall conclusions.

2. The concept of carbon leakage

Carbon leakage is defined as the increase in CO_2 emissions in non-abating countries as the result of CO_2 emission reduction policies in countries that abate CO_2 emissions. Figure 2.1 gives a schematic representation of international climate change policies in the context of an open world economy. The representation is extremely simplified, abstracting from (important) things such as time, the extremely complicated physical relationships between emissions and climate change, the so-called flexibility mechanisms of climate change policy, and other policies. Moreover, the world of Figure 2.1 consists of only two countries, but these two countries can be taken to represent two groups of countries. The aim of this schematic representation is to highlight the most important relationships between the economy and the climate system that are the subject of this study. Arrows depict these relationships.

At the bottom of Figure 2.1 international climate change policies are formulated, motivated by scientific evidence on changes in the earth's climate and man's contributions to these changes. The negotiations among nations at the international level lead to an agreement on emissions reduction targets for individual nations. These individual country targets differ. Figure 2.1 distinguishes between two countries (or groups of countries): country *A* agrees to a binding reduction target, while country *NA* does not.

The internationally agreed reduction targets are adopted by domestic policy-makers who design and implement domestic policies to meet the internationally agreed targets. These policies seek to achieve their goal by affecting production and consumption decisions, directly – through command-and-control instruments – or indirectly – through market-based instruments. The domestic policies will in general lead to changes in the pattern of international trade. For example, as policy measures in country *A* – such as a carbon tax – increase the production costs of its industries that produce CO_2-intensive goods, consumers in country *A* may shift from the more expensive domestic supplies of CO_2-intensive goods to imports of these goods from country *NA* that has not implemented such cost-increasing policies.

The international climate change policy would then indirectly – through changes in national policies and their effects on production and consumption – affect the pattern of international trade. If a producer of CO_2-intensive goods in country *A* decides to move his factory to country *NA* in order to avoid the cost-increasing policy measures in country *A*, then there would also be an effect on international capital and investment flows. Either through changes in trade or investment, country *NA* would now produce a larger share of the world production of CO_2-intensive goods. Hence, all else being equal, the national emissions of country *NA* would rise.

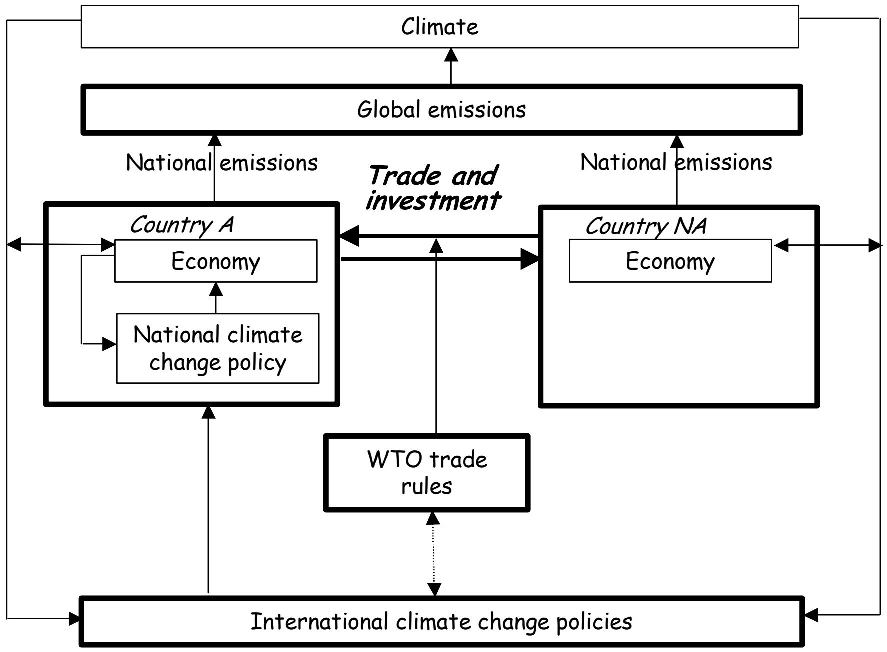

Figure 2.1 A schematic representation of international climate change policies in the context of the world economy.

Given then the CO_2 reduction policy in country *A* and the policy-induced rise in CO_2 emissions in country *NA*, the *rate* of carbon leakage is the ratio of the policy-induced increase of emissions from country *NA* over the reduction of emissions by country *A*. That is, if country A implements measures to reduce emissions by 10 Mt of CO_2 and if the emissions of country *NA* increase by 2 Mt of CO_2 as a result of *A*'s measures, the rate of carbon leakage is

$$\frac{\text{Increase in emissions of country NA}}{\text{Reduction in emissions of country A}} = \frac{2}{10} * 100\% = 20\% \tag{2.1}$$

Carbon leakage is an example of an international pollution externality whose theoretical implications have been studied in the literature (see, e.g., Markusen, 1975; Hoel, 1996). Markusen analyzed how the existence of an international pollution externality (such as CO_2 emissions) would affect the optimality of free trade. He used an analytical two-commodity, two country general equilibrium model.

Take the two countries of figure 2.1 as an example. Country *A* abates CO_2 emissions, while country *NA* does not. Each country produces two commodities, say, food and manufactures. It is assumed that the international pollution externality is a fixed by-product of one of these commodities, say, of manufactures. Country *A* wants to abate the international externality because it is an argument in its social welfare function, that is, the citizens of country *A* have a positive preference for a stable climate. The pollution externality is an additive function of the pollution of *both* countries. It is assumed that country *NA* has no pollution tax or that it does not optimally adjust its tax rate in response to actions of country *A*. In this two-country, two-commodity model, the world price ratio between food and manufactures depends on the foreign offer schedules of the two countries. The simple mechanism is that the more of a commodity that is offered on the world market, the lower will be its price in relation to the other commodity, and *vice versa*. It is assumed, for simplicity, that the domestic price ratio in country *NA* is identical to the world price ratio. Suppose that country *A* is a net exporter of manufactures. The *optimal tariff argument* says that country *A* could improve its terms of trade by *taxing* its exports of manufactures. The export tax will make it less attractive for country *A* manufacturing firms to export and they will offer fewer exports to the world market. In this two-country model total world market supply will fall. The reduced world market supply of manufactures will *increase* the world market price of manufactures in terms of food. Hence, country *A* could buy more food from country *NA* for less manufactures: its terms of trade would increase. In the case that country *A* is a net importer of manufactures, it should, for analogues reasons, tax the imports of manufactures (apply a tariff). Given knowledge on all relevant supply and demand elasticities it is possible to calculate an 'optimal' tariff for country *A* that maximizes its income in terms of manufactures and food.[1]

If the production of manufactures produces an international pollution externality as a by-product, the optimal tariff should not only take account of the terms of trade effect, but also of its effect on foreign pollution. In the case that country *A* is a net exporter of manufactures, the optimal tariff argument advocates an export tax that will increase the world market price ratio of manufactures. This increase in price ratio, however, will also affect the production equilibrium in country *NA*, where resources will be shifted from agriculture to the now more profitable manufactures sector. This shift causes additional pollution, which will negatively affect consumers in country *A* through its effect on the social welfare function. In the case that country *A* is a net importer of manufactures, the 'optimal' tariff has an opposite effect on the world market price ratio, hence decreasing foreign pollution.

Markusen (1975) showed that the optimal tax structure for country *A* in the case of an international externality (e.g., transboundary pollution) consists of a production (or pollution)[2] tax on manufactures *and* a tariff. The optimal production (or pollution) tax is a conventional Pigovian tax[3] whose rate is equal to the domestic marginal damage of the pollution. The tariff is made up of two terms: an optimal tariff term – to take advantage of a country's market power – and a foreign pollution term. The foreign pollution term takes account of the *domestic* environmental damage due to *foreign* emissions. In the case that country *A* is a net exporter of manufactures, the foreign pollution term is negative. This is because the optimal tariff would increase the world market price of manufactures and would therefore stimulate its foreign production and pollution. Because of

1 In this example, the 'optimal' tariff of country *A* reduces the terms of trade of country *B*: country *B* can buy less manufactures in terms of food. The possibility of retaliation by country *B* reduces the *practical* attractiveness of the optimal tariff argument for country *A*.

2 In this case, where pollution is assumed to be a fixed by-product of production, there is no difference between a pollution tax and a production tax.

3 A Pigovian tax is named after the economist A.C. Pigou (1877-1959) who, in 1912, first suggested that governments could, through a mixture of taxes and subsidies, correct market failures caused by external effects or 'internalise the externalities'.

its transboundary nature, a part of this induced foreign pollution would cause damage in country *A*. Country *A* must therefore make a trade-off between improved terms of trade and increased environmental damage. Markusen (1975) showed that it would be optimal for country *A* to reduce its optimal tariff below the rate that would be optimal without the international externality. In the case that country *A* is a net importer of manufactures, its 'optimal' tariff (import tax) on manufactures should be *increased*.

Moreover, Markusen also showed that in case the government cannot make use of the tariff instrument (because its use is for example restricted by international agreement within the General Agreement on Tariffs and Trade (GATT)[4]), the optimal production (or pollution) tax would, in the case of an international externality, in general differ from the conventional Pigovian tax. Hoel (1996) developed this argument further and directly applied it to the climate change policy problem. The major extension of Hoel's model is that he introduced a carbon tax that can be levied on fossil fuels both as a consumption good and as an input to production. Furthermore, he extended the number of commodities that are produced in both countries. Although Hoel himself did not use the term, the foreign pollution effect in Hoel's model can be called carbon leakage. The first-best domestic policy for country *A* in Hoel's model is similar to that of Markusen's: an equal carbon tax for all domestic users of fossil fuels and an 'optimal tariff' that takes account of its impact on international carbon leakage. Hoel (1996) noted that carbon leakage might be large, even if the influence of country *A* on world prices is small (a large elasticity of foreign demand). This is because even a *small* increase in a *large* volume of foreign emissions may generate a *large* increase in foreign emissions relative to the volume of emissions reduction of country *A*.

The analyses of Markusen and Hoel make clear that carbon leakage is an international distortion. The distortion is caused by a lack of global cooperation on climate change policies. Because of this distortion, the optimality of free trade is compromised. In principle, Markusen's optimal tariff could rectify this allocative distortion, but in practice there seems to be little scope for such tariffs because of legal, political and computational/informational reasons. The second-best alternative of differentiating carbon taxes across sectors to take account of carbon leakage may be even more difficult in practice, as Hoel pointed out in a thoughtful discussion of his analytical results (Hoel, 1996).

One computational/informational issue is the actual *size* of carbon leakage. Carbon leakage has been defined as the increase in CO_2 emissions in non-abating countries *as a result* of CO_2 reduction policies in abating countries. The *causality* makes direct measurement extremely difficult. While it is not particularly difficult to measure the increase in CO_2 emissions in any one country, it is extremely difficult to decompose this increase into increases that are i) the result of CO_2 abatement policies in foreign countries and increases that are ii) the result of all other driving forces, including autonomous shifts in the international allocation of CO_2-intensive industries.

---

4 The GATT is one of the trade agreements administered by the World Trade Organization (WTO).

While measuring is and will probably remain problematic, some insights into the *potential* of carbon leakage can be gained by better understanding the mechanisms through which it can occur. The next section discusses these mechanisms.

3. The 'channels' of carbon leakage

In the literature, a number of distinct mechanisms or 'channels' of carbon leakage have been identified. The most important channels can be grouped under the following four headings:

1. International trade in energy goods;
2. International trade in other goods and services;
3. International trade in factors of production;
4. International interaction among government policies.

Below, the specific mechanisms underlying each channel are explained and selected research findings on carbon leakage are presented for each channel.

In addition to the channels discussed in this report, there may also be so-called technology spillovers. These are the subjects, however, of the accompanying report by Sijm (2004b).

3.1 International trade in energy goods

CO_2 reduction policies in a large region may well have a significant negative effect on the world demand for carbon-rich fossil fuels, causing a possible fall in their world market prices. Falling prices could increase the demand for carbon-rich fuels in the rest of the world, thus increasing foreign CO_2 emissions and enlarging carbon leakage. OECD (1999) referred to this mechanism of carbon leakage as the 'energy channel'. Of key relevance to the quantitative importance of the energy channel are assumptions on the effects of CO_2 reduction policies on the demand for specific fuels, changes in world market prices, the supply response of fossil fuel producers, and the demand response of energy users in non-constrained countries. These assumptions are summarized in the parameters that reflect the:

- Trade elasticities of fossil fuels;
- Supply elasticities of fossil fuels;
- Substitution elasticities in production among different fuels and between fuels and other factors of production; and
- The structure of the energy market.

Trade elasticities reflect the level of integration of the world market for a specific product. With large trade elasticities, market changes in one country or region give rise to relatively large effects on world trade and therefore to relatively large market changes in other regions. Hence, all else being equal, large trade elasticities for fossil fuels generate a large rate of leakage.

The relevance of the supply elasticity of fossil fuels, and thus, indirectly, the supply elasticity of carbon becomes clear if one realizes that, ultimately, the volume of energy-related carbon that is emitted to the atmosphere is almost exactly equal[5] to the volume of

---

[5] Fossil fuel combustion implies oxidising the carbon contained in the fuel; most carbon is emitted as CO2, but a small and variable part as CO, VOCs and other compounds.

carbon contained in fossil fuels that is mined or extracted from the earth and supplied to the market and combusted. Assuming elastic demand, if the supply of fossil fuels (and thus carbon) would be completely inelastic, there is no quantity response to a price change, and any amount of CO_2 emission reduction in some region must be matched by an equal amount of additional emissions in another region. Hence, the more *inelastic* the supply elasticity, the *higher* the rate of carbon leakage and *vice versa* (OECD, 1999). The sensitivity of carbon leakage to supply elasticities of fossil fuels, and especially to the supply elasticity of coal, is generally acknowledged in the literature (Light, Kolstad, & Rutherford, 1999).

Coal has the highest carbon content of fossil fuels, and changes in the international trade in coal may therefore have a relatively large effect on carbon leakage. It is sometimes argued that national coal markets are not very well integrated into a world coal market. Reasons for this include its relatively high transportation costs and the cost and time that are needed for building-up infrastructure for storage and distribution. If national markets are not well integrated, a lower price of coal in, for example, the U.S. or Australia would not directly lead to lower prices of coal in, for example, China or India and would therefore not directly lead to additional demand for coal (and associated emissions) in these non-Annex I countries. In such a case, 'coal leakage' may be minimal, even if its elasticity of supply would be very small. If the demand for coal in abating countries would fall, a small elasticity of supply would mean that its price would have to fall sharply in order to restore the equilibrium between demand and supply. Without a proper world market and hence low trade elasticities, the price fall could be restricted to the national market.[6]

The elasticity of substitution between inputs in the production of goods and services can also play a role in the explanation of carbon leakage. There are two elasticities that are potentially important:

- The elasticity of substitution among fuels with a different carbon content: the inter-fuel elasticity;
- The elasticity of substitution between energy and other factors of production (capital, labor): the inter-factor elasticity.

Burniaux and Oliveira Martins (2000) found a U-shaped relationship between inter-fuel substitution elasticity and the rate of leakage. At relatively low inter-fuel substitution elasticities, the demand for all carbon-based fuels in abating countries will decrease almost proportionally. Given the supply elasticities in their economic model[7] (high for coal, lower for oil), the world market price of oil will fall more than the price of coal, and producers in non-abating countries will shift their fuel mix towards the cheaper oil to the extent that is determined by *their* inter-fuel substitution possibilities. The net result is that at relatively low values of the inter-fuel substitution elasticity, an *increase* of that elasticity leads to a *reduction* of leakage. At relatively high inter-fuel substitution elastic-

6 This would lead to an increased *national* uptake of coal, but this would not lead to higher national emissions because these emissions are assumed to be 'capped' by the Kyoto Protocol. This could lead to substitution between coal and other fuels and subsequent effects on the world markets of these other fuels. These and related interactions between markets are major reasons for the frequent use of applied general equilibrium models to study carbon leakage.

7 The GREEN model, see Appendix.

ities, the demand for fossil fuels in abating countries will decrease *in proportion to the carbon-content* of fuels. That is, the demand for coal will fall more than that for oil and gas. The demand for oil and gas may even increase. Given the relative low elasticity of supply of oil and gas, their prices might rise relative to the price of coal. The price effect is then the reverse of that in the previous case, and demand for coal will increase in the non-abating countries, inducing an increase in carbon leakage. At these higher values of inter-fuel substitution elasticity, an *increase* in that elasticity leads to an *increase* in leakage. Similar results are found for the *inter-factor* elasticity of substitution (Burniaux & Oliveira Martins, 2000).

It is sometimes assumed that energy producers (such as those participating in OPEC) have enough market power to maintain energy prices by restricting output in the face of falling demand. In such a case, the elasticity of supply might be so large as to prevent any price effects. Babiker and Jacoby (1999) have examined this assumption, but found that OPEC coordination action is not very likely because "the [high] elasticities of demand of importing countries, and of supply of non-OPEC exporters, combine to produce a market condition where efforts to resist a fall in oil price resulting from Kyoto restrictions lead to still lower OPEC revenue." (Babiker & Jacoby, 1999: 15). In other words, Babiker and Jacoby argued that under these market conditions OPEC would in fact be worse off if it tried to maintain oil prices by reducing supply.

3.2 International trade in other goods and services

Carbon reduction policies may increase the production costs of carbon-intensive industries in abating countries and may therefore increase the selling prices of their goods. The demand for these goods may shift to relatively cheaper sources in non-abating countries whose costs have not been affected by carbon reduction policies. Hence, comparative advantage would shift to industries in non-abating countries and this would affect production and trade. All else being equal, this would increase CO_2 emissions in these non-abating countries. Two parameters are of key importance with respect to carbon leakage through this 'trade channel'. They are:

- The substitution elasticity between domestic and imported goods;
- The degree of international capital mobility; and
- The market structure.

The elasticity of substitution between domestic and imported goods (and between imported goods of different origin) in applied general equilibrium (AGE) models is typically finite. This is a modeler's convention, following the approach suggested by Armington (1969) to treat goods of different origin as different, non-homogeneous goods.[8] The elasticity of substitution is therefore also called the Armington elasticity. Burniaux and Oliveira Martins (2000) found that carbon leakage is not very sensitive to the value of the Armington elasticities. This finding is, however, contested by others and may be model-specific. For example, Böhringer and Rutherford (2000) and Paltsev (2001) found

[8] The Armington specification of international trade has the advantage that intra-industry trade can be accounted for and that unrealistically strong specialization effects due to changes in trade policy are avoided. In AGE models on CO_2 reduction policies, only crude oil is often assumed to be a perfectly homogeneous good.

that the values of the Armington elasticities have a significant impact on the rate of leakage: the larger the trade elasticities (the more homogeneous the goods), the larger the rate of leakage.

While the above studies, with the exception of Babiker and Jacoby (1999), examined carbon leakage in perfectly competitive markets, different mechanisms are responsible for carbon leakage in imperfectly competitive markets. Examples of such imperfectly competitive markets are oligopolistic markets and monopolistic competition.

In an oligopolistic market, a small number of firms compete directly with each other. In making price and quantity decisions a firm in such a market must take account, not only of responses of consumers, but also of the responses of their competitors, whose responses depend, in their turn, on their expectations of the firm's behavior (Krugman & Obstfeld, 2000: Chapter 6). If a firm in an oligopolistic international market reduces its supply because of the cost-increasing effects of CO_2 reduction policies in one country, competitors in other countries may have a direct strategic incentive to expand their supplies (and emissions). An overview of carbon leakage through oligopolistic interaction among firms is given by Ulph (1997). An important result of the oligopolistic interaction research is that the *type* of policy instrument matters in these circumstances, i.e., the incentive for strategic environmental policy is larger when emission taxes are used than when emission standards (fixed emissions ceilings) are used. This is the case because the purpose of the strategic intervention is to let the output of a domestic industry expand at the expense of foreign competitors. In the case of a fixed emission tax per unit of pollution, the environmental costs of a firm rise proportionally with output. In the case of an emission standard, environmental costs may rise more-than-proportionally with output if the marginal abatement cost curve is sloping upwards (each additional unit of abatement is more expensive than the previous unit).

Gürtzen and Rauscher (2000) examined the effects of climate change policies in the case of monopolistic competition. In a monopolistic market structure, firms produce a continuum of differentiated goods; each firm produces a specific variety (say, a "Volvo" car). Consumers prefer variety over uniformity. In the case of a CO_2 reduction policy, the production costs of firms increase and the number of domestic firms that can operate profitably decreases.[9] This would lead to a decrease of variety in the domestic market. Because a decrease of variety reduces the substitution possibilities between any two varieties, the mark-ups that (foreign) producers can charge in excess of marginal costs increases [10] and therefore the number of foreign firms (and foreign emissions) increases. Hence, this market structure effect may be an additional channel of carbon leakage.

Carbon leakage through the trade channel can also be influenced by the degree of international capital mobility. As is well known from the international trade literature, trade

---

9 Gürtzen and Rauscher (2000) also discussed conditions under which the number of firms increases due to a tightening of environmental policy. Although this may indeed be a consequence of their model, this possibility seems to be extremely 'counter-intuitive' and of little relevance. An *increase* in the number of monopolistic firms in the abating country may lead to negative leakage.

10 The mark-up that a monopolistic firm can charge is inversely related to the absolute value of the demand elasticity of its produced variety.

in goods and trade in factors of production (e.g., capital) can be substitutes or complements. If trade in goods and trade in factors are substitutes, an increase in one will reduce the other. For example, starting from a situation with free trade in goods, but restrictions on the free international movement of capital, the liberalization of the international capital market would reduce the international trade in goods. A car company may, for example, start a foreign subsidiary to produce for a foreign market instead of shipping the cars abroad from its home production plant. If trade in goods and trade in factors of production are complements, an increase in one will increase the other. For example, the car company may invest in a dealer network in the foreign country (a capital transfer) to increase the sale of its home-made cars (Markusen, Melvin, Kaempfer et al., 1995: chapter 21; Rauscher, 1997: Chapter 3). Thus, international capital mobility can reduce or increase international trade in goods and services and hence carbon leakage through this channel.

The channel of international trade in factors of production is also interesting in its own right. The next paragraph considers international trade in factors of production in more detail.

3.3 International trade in factors of production

Carbon reduction policies can reduce the productivity of factors that are employed in the production of fossil fuels or energy-intensive commodities. This may lead to an international reallocation of such factors to countries without such policies. In the political arena, the effect of climate and energy policies on international capital reallocation is the “channel” that is most discussed and feared.[11] Although the effect of international capital mobility on carbon leakage would seem to be fairly obvious, its potential importance in current climate change policies is an issue of some controversy in the academic literature.

Conventional economic analysis of trade and environment interactions has been challenged on the grounds that it did not take (enough) account of international capital mobility, a phenomenon that is supposedly rapidly growing in importance and is closely linked to the issue of globalization. In a critical assessment of conventional analysis, Daly (1993) asserted that the conclusions of this conventional analysis hinged on the critical assumption of the immobility of factors of production (especially capital). He basically asserted that the theorem of *comparative* advantage would be dependent upon the assumption of the immobility of factors, while mobility of factors would imply that the international allocation of production would be governed by *absolute* advantage (Daly, 1993). The idea that the assumption of international immobility of capital is critical to

[11] For example, in the early 1990s the Dutch Wolfson Commission predicted a large-scale reallocation of energy-intensive industries (or parts thereof) if energy taxes of the size that were under discussion then would be implemented (Herzberg & Minne, 1992). To put the findings of the Wolfson Commission in perspective, two remarks can be made. First, the Commission examined the effect of energy taxes (not CO_2 taxes) so that substitution possibilities in production within firms would be limited (and were in fact neglected), and second, the size of the energy taxes examined (up to 100 percent of then current energy prices) was orders-of-magnitude larger than the implied increases in energy prices because of CO_2 emissions restrictions that are currently under discussion.

the theory of international trade and therefore also to its extensions to environmental externalities, is still echoed in more recent academic literature (see, e.g., Batra, Beladi, & Frasca, 1998).

The theory of international trade has, however, dealt with the international mobility of factors. Already in 1957, Mundell (1957) showed that trade in goods and trade in factors were perfect substitutes in the classical Heckscher-Ohlin (comparative advantage) model of international trade. Mundell showed that in this model, equalization of commodity prices and factor prices could be brought about by trade in goods without capital mobility or by capital mobility without trade in goods. If both trade in goods and trade in factors lead to the same prices and allocation of resources, there can also be no differences in environmental outcomes between the two. Hence, it is justified in this kind of model to only consider trade in goods alone, or only trade in factors, or, indeed, any combination of both.

When, however, some assumptions of the standard Heckscher-Ohlin model of international trade are relaxed, e.g., perfect competition, common level of technology across countries, constant-returns-to-scale technologies, and the absence of domestic distortions, the equivalence between trade in goods and trade in factors may break down. In some cases, trade in goods and trade in factors of production may even become *complementary* (Markusen et al., 1995). Springer (2000) discussed the exact conditions under which trade in goods and trade in factors can be complements rather than substitutes. In the case of complementarity, the internationally allocative effects of climate change policies may be magnified by international capital mobility. Neglecting this magnifying effect could lead to a biased (under-) estimate of international carbon leakage.

The location choice of firms is the subject of an extensive body of research that is known as 'new economic geography' (see for instance Fujita et al., 1999). Although this literature is not directly related to environmental issues, its overall conclusions are relevant (see also Elbers and Withagen, 2004) or transferable to the environmental literature. Baldwin and Krugman (2000) for instance analyzed the effect of corporate taxation in the presence of agglomeration forces in falling trade costs. With agglomeration forces, the location choice of a firm is not irrelevant. These authors showed for instance that "integration need not lead to falling tax rates, and might well be consistent with the maintenance of large welfare states". If one is willing to equate corporate taxation with environmental taxation (or carbon policies), the presence of agglomeration forces might be one element that would limit the leakage problem. Other literature that could be mentioned here includes Albrecht (1998), Jeppesen and Folmer (2001), and List et al. (2003). In general, imperfect competition and agglomeration effects could *reduce* or *increase* relocation effects and carbon leakage due to environmental policies

The potential environmental impact of international capital mobility has been well recognized in the theoretical literature, also within the framework of the (broadly-defined) comparative advantage model of international trade. The *extent* of this potential impact has been the subject of econometric estimation and model simulation.

The first question that needs to be answered relates to the international mobility of capital: how mobile is capital internationally? In the popular image capital is extremely mobile across countries, but research has found surprisingly little evidence of international mobility of real capital. Researchers have found limited international portfolio diversification, a high correlation between domestic savings and investments and significant real interest differentials across countries (Gordon & Bovenberg, 1996). Wang and Winters (2001) surveyed an extensive literature on the impacts of locational factors on foreign direct investment (FDI) decisions of multilateral companies. These locational factors include tax concessions and government policies, labor cost differentials and environmental factors. Wang and Winters concluded from this literature i) that the relative level of taxation is just one variable that affects FDI, but is rarely a primary motive, ii) that labor costs differentials (accounting for differences in labor productivity) is also a factor, though not of major significance, and iii) that the studies seem to suggest "quite strongly" that there is little evidence for industrial flight from countries with strict environmental standards. The authors therefore conjectured that "it would be very difficult to believe that imposing a carbon tax (of around 100 USD/tC) in the OECD will cause serious industrial flight from OECD to non-OECD countries." (Wang & Winters, 2001 :151).

The empirical literature on the effect of environmental regulation on firm relocation is ambiguous and highly sensitive to empirical specification, data (cross-sectional or panel data, level of aggregation), and a host of specific assumptions regarding the exact design of the policy measure and other variables (Jeppeson, List, and Folmer, 2002). Jeppeson, List and Folmer concluded on the basis of an extensive meta-analysis of the empirical literature that it is as yet impossible to draw any firm conclusions on the effect of environmental regulations on [international] capital flows (Jeppeson, List, and Folmer, 2002: 36).

Simulation studies with applied general equilibrium models seem to suggest that capital flight from abating to non-abating countries will not be of major significance in the context of the Kyoto Protocol, at least not during the time up to the first commitment period (2008-2012) (McKibbin, Ross, Shackleton et al., 1999; Burniaux et al., 2000; Babiker, 2001; Burniaux, 2001; Paltsev, 2001). One major factor is simply that the 'absorptive capacity' of developing countries for foreign capital is considered to be relatively small (McKibbin et al., 1999). Another factor may be that carbon leakage in non-abating countries would be basically 'self-financed' because of the relative fall of fossil fuel prices on the world market (Babiker, 2001). Because of reduced input costs (for fuels) and stable or higher output prices, energy-intensive industries in non-abating countries would see their profits rise and could therefore easily finance the expansion of their production out of these extra profits. In this sense, carbon leakage would not really require any additional capital flows.

While there is nearly overall consensus on the limited contribution of capital mobility to carbon leakage in the near term, Burnieaux (2001) asserted that the relocation of international investment may well become the dominant source of carbon leakage in the more distant future (after 2010) in the absence of major breakthroughs in renewable energy technologies. In a paper for the International Energy Agency, Gielen and Karbuz (2003) also expected that industrial relocation might be the primary source of leakage in the long term. When CO_2 reduction policies would become more stringent, relocation could become a serious threat, especially to specific, CO_2-intensive sectors.

3.4 International interaction among government policies

Up till this point in this overview, the policies of abating and non-abating countries were assumed to be given: a country either had a given emissions reduction target or not. However, when this assumption is relaxed and countries may be assumed to choose carbon reduction policies on the basis of some trade-off between costs and benefits, this may also affect carbon leakage. Copeland and Taylor (2003) examined the response of a country to another country's CO_2 reduction policies, when the citizens of this country would not only be interested in the consumption of market goods and services, but would also derive utility from environmental services, such as those provided by a stable climate. The government of this country is assumed to maximize the utility or welfare of its citizens. Copeland and Taylor (2003) showed that the response of the country contains two additional terms in addition to the changes in trade and investments that were discussed above:[12]

The first additional term measures the *free rider effect*. The free rider effect captures the idea that one's willingness to contribute to the provision of a public good is negatively affected by the willingness of others to contribute to this good. The optimal level of CO_2 reduction for a country is that level that equates the marginal abatement costs of emissions reduction to the marginal damages of CO_2 emissions, which is a function of both domestic and foreign emissions. If foreign emissions fall, the marginal damages of CO_2 emissions fall, and hence the optimal level of domestic abatement falls.[13] The free rider effect is the only term of the response function that would also exist in autarky (in the absence of international trade). In autarky, domestic and foreign emissions are strategic substitutes. That is, the welfare-maximizing strategy of a government is to react on a foreign change in emissions by a change in domestic emissions in the opposite direction. Hence, through the free rider effect, the domestic country would always *increase* its emissions due to a foreign emissions reduction policy.

The second additional term is a pure income effect, which Copeland and Taylor (2003) called the 'bootstrapping effect'. Whether the bootstrapping effect is positive or negative depends on the trading pattern of the domestic country. If the domestic country is a net exporter of CO_2-intensive goods (or a net importer of fossil fuels), its terms-of-trade will improve and its real income will rise (its domestic production has increased in value at world market prices: one unit of exports will buy more imports). If environmental quality is a normal good, a rise in income will increases the demand for environmental quality so the government will tighten environmental policy and reduce emissions. Conversely, if the domestic country is a net importer of CO_2-intensive goods (or a net exporter of fossil fuels), its real income will fall, demand for environmental quality will fall, and emissions will increase. The effect of the bootstrapping effect on carbon leakage is thus ambiguous.

---

[12] In fact, Copeland and Taylor also distinguish a substitution effect in consumption, that would increase the demand for the environmental good (climate quality) if the relative prices of consumption goods would rise (because of environmental taxes).

[13] Only, of course, under certain (but fairly standard) assumptions on the signs of the first derivatives of the abatement and damage functions.

All terms together (trade/investment, free-riding, bootstrapping) determine the ‘optimal’ (i.e., welfare-maximizing) change in domestic emissions in response to a foreign reduction policy. The sign of this ‘optimal’ change is ambiguous. Copeland and Taylor (2003) stressed that carbon leakage *might* be negative under the assumption of endogenous policies, when the bootstrapping effect dominates the free rider and the trade/investment effects.

How relevant is the assumption of endogenous policies to international climate change policies? Copeland and Taylor argued that while the graduation of developing countries into the abating countries under the Kyoto Protocol (the Annex I countries) “may seem unlikely at present, it is unwise to rule out such possibilities *a priori* especially when the policy experiment under consideration involves extremely large time horizons and potentially large changes in income.” (Copeland & Taylor, 2003: 17).

3.5 Conclusions

A number of channels of carbon leakage may be distinguished:

- Through changes in the pattern of international trade of energy commodities;
- Through changes in the pattern of international trade of CO_2-intensive goods and services;
- Through the international relocation of capital;
- Through the interactions of government policies.

Many studies have analyzed one or more of these channels, both from theoretical and empirical perspectives. It is not easy to summarize the main findings of scientific research in this area, as there is ample discussion, controversy and speculation, and there is not much hard empirical evidence to go by. However, a few points can be mentioned.

Most applied modelers seem to agree that the ‘energy commodity’ channel is quantitatively the most important channel, at least in the short to medium term. It should be noted, however, that most ‘leakage’ studies do not take much account of possible strategic behavior of large energy suppliers. If suppliers of fossil fuels could effectively restrict their total supply in response to diminishing demand in an attempt to stabilize market prices, there would be a smaller price effect and hence less leakage.

The effect of trade in CO_2-intensive goods and services on carbon leakage is generally believed to be limited, but here too is a need for studies that employ alternative assumptions on market structure.

A large amount of controversy exists on the effect of international reallocation of capital on carbon leakage. While some modelers assume that the contribution of capital mobility will be very limited (and mainly restricted to capital flows among the more advanced Annex I countries), others stress the importance of international capital mobility in this respect, especially in the longer term.

At least from a theoretical point of view, a ‘negative’ rate of leakage is very well possible, but there is not yet much support for this thesis from more empirical research.

4. The potential size of carbon leakage

The potential size of carbon leakage has been estimated by a number of economic models. In this section, a number of these estimates are presented. Differences between the estimates will, if possible, be related to differences in the underlying models, and especially by differences in their relevant parameters. These include the parameters that were discussed in Chapter 3. This chapter ends with a discussion on the sources of variance among leakage estimates.

4.1 Economic models

For an *ex-ante* estimate of carbon leakage, one has to rely on economic models. As yet, carbon leakage has not been measured econometrically, and cannot be because no country has embarked on a serious emission reduction policy. Economic models are simplifications of economic reality and their results should be interpreted with caution. There are various types of economic models. Analytical models, such as those of Markusen and Hoel that were discussed in Chapter 2, may reveal the causes and consequences of carbon leakage, but they cannot estimate its size. Numerical models include macro-econometric and applied general equilibrium (AGE) models. Both types of models have their specific strengths and weaknesses. The main difference between these types of models is that AGE models explicitly model the behavior of each economic agent that is distinguished in the model, while macro-econometric models base their equations on the historically observed (and econometrically estimated) outcomes of this behavior in markets. While AGE models are more firmly based in micro-economic theory, macro-econometric models are sometimes praised for their greater level of realism. All model estimates of carbon leakage that are presented below are derived by AGE models, although one of the models (G-Cubed) can perhaps better be described as a hybrid between an AGE and a macro-econometric model. For this assessment no estimates of carbon leakage were found that were derived by strictly macro-econometric models.

4.2 Model estimates

Studies on carbon leakage provide no consensus on the *size* and *distribution* of the leakages generated by the implementation of the Kyoto Protocol (OECD, 1999). Estimates of the size of leakage vary considerably. Table 4.1 reports on a number of estimates of carbon leakage between the original Annex I and non-Annex I countries of the Kyoto Protocol under the assumption that there will be no emissions trading among Annex I countries. The rates of leakage range between 5 percent in OECD's GREEN model to 20 – 21 percent in WorldScan and the model by Light et al.

Table 4.1 Some model estimates of rates of carbon leakage of CO_2 reductions in Annex I countries according to Kyoto targets, without emissions trading.

Carbon leakage rates in a number of models	
Model	Carbon leakage (%)
Light et al. 1999	21 %
WorldScan	20 %
MERGE	20 %
GTAP-E	15%
GTAP-EG	12%
MIT-EPPA	6 %
G-Cubed	6 %
GREEN	5 %

Sources: Burniaux and Oliveira Martins (2000), Paltsev (2001), and Kuik and Gerlagh (2003).

It was suggested in Chapter 3, that some part of the differences could be explained by examining the model's assumptions on trade elasticities, especially those of energy goods, and supply elasticities of fossil fuels, especially those of coal. Table 4.2 presents trade and supply elasticities for a number of the above-mentioned models. Most models make use of the 'Armington approach' to model substitution in trade (Armington, 1969). Commonly, a difference is made between the elasticity of substitution of imports from different sources, σ_M, and the elasticity of substitution between the "composite" import and the domestic good, σ_D. The convention in most models is to use an elasticity of substitution of imports from different sources, σ_M, of twice the value of the elasticity of substitution between the composite import and the domestic good, σ_D. This has been reported as an "empirical regularity" (Hertel, 1997) and has not been rejected by recent empirical work (Hertel, Hummels, Ivanic et al., 2003; Liu, Arndt, & Hertel, 2001). The Armington substitution elasticities between domestic and imported goods (σ_D) is infinity when considering perfectly homogeneous goods. In the GREEN model, oil is treated as such. In GTAP-E, oil is fairly elastic (σ_D=10).

The supply elasticities of fossil fuels (η_S) indicate the rate of decreasing returns in the production of fossil fuels. There is some disagreement among models: while GREEN and MIT-EPPA assume an elastic supply response for coal and a less elastic supply for gas, WorldScan assumes the reverse. It is clear that additional research on (long-term) supply response of fossil fuel sectors could prove beneficial.

Table 4.2 Key elasticities in some AGE models that have been used to estimate carbon leakage.

	σ_D: Armington substitution between domestic and imported goods		σ_M: Armington substitution among imports		η_S: supply elasticity		
Model	Oil	Other goods	Oil	Other goods	Coal	Oil	Gas
Light et al.	4	4	8	8	0.5	0.5	0.5
WorldScan	16	2-10 [1]			1.8	1.9	9.0
MERGE [2]							
GTAP-E	10	2.8	20	5.6	0.5	0.5	0.5 [3]
GTAP-EG	4	4	8	8	1.0	1.0	1.0
MIT-EPPA	3	3 [4]	4	5 [5]	5.4 [6]	1.2 [7]	1.8
G-Cubed	1	1	1	1	– [8]	– [8]	– [8]
GREEN	∞	4	∞	5	20.0	1.0	1.0

1) Substitution elasticity of 2 for coal and gas, 5 for services, 6 for consumption goods, and 10 for agricultural commodities.
2) MERGE has a different structure, see text.
3) For gas extraction, excluding transport and distribution.
4) Except electricity: 0.3
5) Except electricity: 0.5, other energy goods: 4, refined oil: 6.
6) Except for China: 4.4 and India: 3.4.
7) Except for energy exporting developing countries: 0.3 and Former Soviet Union: 0.6.
8) Could not be found in the documentation of the model.

Comparing the elasticities in Table 4.2 to the leakage rates in Table 4.1 it appears that variations in assumptions on the supply elasticities of coal can explain differences in leakage rates to a certain extent. The models with the lowest rate of leakage (GREEN and MIT-EPPA) have the highest supply elasticities of coal ($\eta_s = 20$ and 5.4, respectively). The reverse is not completely true, however. While Light et al. indeed combines a high rate of leakage (21%) with a low elasticity of supply of coal ($\eta_s = 0.5$), WorldScan combines a high rate of leakage (20%) with a relatively high supply elasticity of coal ($\eta_s = 1.8$).

In was suggested in Chapter 3 that assumptions on trade elasticities in the models could also explain some of the variation in the leakage results. Many models take the assumption that oil is a homogeneous commodity with either infinite (GREEN) of very high (WorldScan, GTAP-E) trade elasticities. Trade elasticities for other energy goods (coal and gas) range from $\sigma_D = 1$ in G-Cubed to $\sigma_D = 4$ in Light et al., GREEN and GTAP-EG. It thus seems that assumptions on trade elasticities of energy goods do not explain differences in leakage across models very well. The same seems to apply to differences in trade elasticities of other goods.

MERGE and G-Cubed are somewhat apart from the other models. MERGE combines a detailed energy supply sector and an aggregate representation of the rest of the economy. Trade among regions is only possible for oil, gas and a composite ‘energy-intensive basic materials’ good. The energy channel and the non-energy trade channel (energy-intensive basic materials) each account for about half of the leakage in 2010.[14] Policy-

---

14 See Manne and Richels (1999), Figure 7.

induced relocation of production in energy-intensive basic materials is determined by the equalization of marginal supply costs across regions, assuming an upward sloping supply curve in each region and assuming no change in demand. G-Cubed is the only model of Table 4.1 that explicitly accounts for international borrowing and lending of countries in relation to their current account deficits and surpluses. Related to this focus on financial markets is the result that the international relocation of (financial) capital is an important indirect source of leakage in G-Cubed. G-Cubed, however, predicts a low rate of leakage to non-Annex I countries because it assumes a low absorptive capacity for capital investments in these countries in the short to medium term. The models of Table 4.1 are briefly discussed in the Appendix to this chapter.

What other factors could explain the differences in leakage rate across the models? The Third Assessment Report of IPCC (2001) also reported a range of leakage estimates in the literature of 5–20 percent. It noticed that some reduction in variance among the estimates of different studies has occurred in recent years. IPCC was, however, reluctant to accept this reduction of variance as a sign of increased scientific certainty on this issue. IPCC (2001) flagged the following parameters to be of critical significance to carbon leakage:

- Trade elasticities;
- Input substitution elasticities in the electricity and iron and steel industries in Annex I regions;
- Degree of competitiveness in the world oil market;
- International emissions trading.

Burniaux and Oliveira Martins (2000) and Burniaux (2001) offered a slightly different list of critical parameters. At the top of their list was the *supply elasticity* of fossil fuels, especially coal. Light et al. (1999) and Burniaux (2001) also stressed the importance for the size of carbon leakage of assumptions on the integration of the international coal market. Hence, there seems to be little consensus on the size of carbon leakage as well as on the key parameters that might influence it. Apart from differences in key elasticities, Barker and Johnstone (1998) identified additional sources of differences among the models that can lead to different predictions of carbon leakage: assumptions on exchange rate and monetary policies, international factor mobility, market power in the oil sector, expectations and adjustment, revenue recycling, the level of aggregation of regions, sectors and fuels, technological change and strategic behavior. It is clear that no single study can address all these issues at the same time.

Grubb et al. (2002) cited the IPCC range of 5–20 percent for the leakage rate, but they commented that this rate would probably be lower in reality, because they assumed a relatively high supply elasticity of international coal and oil supply relative to the elasticity of demand and active government intervention to minimize industrial reallocation (or trade effects for the energy-intensive sectors) (Grubb, Hope, & Fouquet, 2002).

Paltsev (2001) carried out a *decomposition* of carbon leakage to regions and industries. Paltsev's aim was not to estimate the *size* of carbon leakage, but to examine which regions and industries would be most sensitive to leakage. Paltsev accepted that the absolute size of carbon leakage is still very uncertain and, with the current tools of analysis, mainly dependent upon model structure and parameterization. Using the GTAP-EG model, he found a leakage rate of 11.5 per cent as a central estimate for a policy scenario that was based on the full implementation of the Kyoto Protocol (including participation by the US). More important than this central estimate, however, Paltsev found that leakage would be most sensitive to CO_2 reduction measures in the chemicals and iron and steel industries. With respect to geographical distribution, actions in the European Union could be responsible for about half of global carbon leakage (36-51%), followed by the United States (28-34%) and Japan (13-18%). On the receiving side, the largest increases in CO_2 emissions could be expected in China (24-32% of carbon leakage) and the Middle East (24-30%) (Paltsev, 2001).

Kuik and Gerlagh (2003) studied the effects of trade liberalization on carbon leakage. They found that GTAP-E's central estimate of carbon leakage of 11 percent would increase by 4 percentage-points to 15 percent if the global tariff reductions of the Uruguay Round of multilateral trade negotiations of the WTO would be taken into account (see also Section 4.3 below).

The estimates of Table 4.1 apply to carbon leakage between the original Annex I and non-Annex I countries of the Kyoto Protocol. The estimates do not include potential leakage to Annex I countries without binding emissions reduction targets (Eastern European countries and FSU), nor to Annex I countries that have subsequently withdrawn from the Protocol, such as the US and Australia. Without effective CO_2 mitigation policies in these countries, the overall leakage rate from, for example, Europe might be higher. In their assessment of the Kyoto protocol, Lejour and Manders (1999), estimated leakage to unconstrained Eastern European countries at 3.3 percent. Bollen et al. (2002) estimated that non-participation of the USA to the Kyoto Protocol could increase leakage from the participating countries from 14 to 22 percent.

4.3 Carbon leakage and trade liberalization

Carbon leakage has been identified as an international distortion in Chapter 2. Several mechanisms or "channels" of carbon leakage have been identified in Chapter 3. The common characteristic of all these channels is that they operate through international trade in goods or factors. It is obvious that there would be no leakage without international trade. This does not imply that international trade is the *cause* of carbon leakage, but it is a necessary condition for leakage. A question that would seem to logically follow from this observation is whether a certain degree of *liberalization* of trade, as for example through multilateral trade agreements, would increase the rate of carbon leakage. If this would be the case, the conventional gains-from-trade would be compromised and there would perhaps be a reason for negotiators of multilateral or other free trade agreements to take the effect of trade liberalization on carbon leakage into account when formulating their agreements (or at least to coordinate their actions with environmental policy-makers).

Before an overview of the literature on this subject is presented, it should be noted that the theory of international trade is built on two important ideas from the founding fathers of economics. The first is the idea of comparative advantage, developed by David Ricardo (1821), who argued that *relative* cost differences between countries (and not absolute cost differences) were the cause of profitable international trade.[15] The second idea, in fact the older one, is the concept of economies of scale, which can be traced back to Adam Smith (1776), and his proposition that the degree of profitable specialization of labor depends on the size of the market. In modern times, the idea of comparative advantage has been formalized first, resulting in the now classical Heckscher-Ohlin theorem of international trade. For some decades, the theory of international trade has been, in fact, a theory of comparative advantage. The theoretical formalization of the idea of economies of scale as an important cause of trade is from a later date. Although the importance of both ideas is now fully recognized in the theory of international trade (see, e.g., Krugman and Obstfeld (2000)), the idea of comparative advantage has led to the most developed and consistent theoretical models of international trade, and underlies most of the applied modeling in this field. The idea of economies of scale has led to a series of important and illuminating theoretical models, but as yet, not to a unified and coherent model with the same power as the comparative advantage model. Most of the environment-and-trade literature is built on the classical, comparative-advantage model of international trade.

The effects of freer trade on the environment have been the subject of a significant body of theoretical and empirical research. It is beyond the scope of this section to give an exhaustive overview of this literature. For excellent overviews the interested reader is referred to Rauscher (1997) and Dean (1992; 2002). In the early 1970s, several authors began to examine the consequences of the existence of environmental externalities for standard trade theory, especially with respect to the theorem of comparative advantage and the gains from trade. Markusen (1975)[16] and Pethig (1976) were among the first to formalize the problem of environmental externalities in the standard two-sector, two-country general equilibrium model of international trade. A general conclusion from this literature was that domestic environmental externalities could reduce the conventional gains from trade, but that the first-best solution to deal with this problem was not to restrict trade, but to 'internalize' the environmental externalities through appropriate government intervention. This work could therefore also be read as a theoretical justification of OECD's famous 'Polluter Pays Principle' of 1972.

Theoretical and applied work on the environmental effects of trade liberalization were greatly stimulated by the controversies surrounding the preparations and conclusion of the North American Free Trade Agreement (NAFTA) in the early 1990s. One important study of that time decomposed the impacts of trade liberalization on the environment into three effects: the effects of changes in scale, composition and technique (Grossman & Krueger, 1991). The general ambiguity of theoretical models that dealt with environment-and-trade interactions could be explained by the fact that in many situations the three distinct effects would not all point in the same direction. The scale effect is proportionally related to the overall expansion (or contraction) of an economy after the liberali-

---

15 For an excellent, non-technical and very amusing introduction to the idea of comparative advantage, see Krugman (2001).

16 For a discussion of Markusen's paper, see Chapter 2. Markusen's paper stands somewhat apart from other early contributions as it dealt explicitly with *international* environmental externalities, while the other contributions primarily dealt with *domestic* environmental externalities.

zation of trade. In most cases this effect will be positive, hence pollution will increase. The composition effect is related to the changes in sectoral composition of an economy after trade liberalization. It may be the case that an economy moves towards an increased specialization in polluting sectors, or, alternatively, towards clean sectors. Finally, the technique effect is related to the mix of polluting and clean inputs that is used by the economy. Trade liberalization may affect this mix in two ways. First, trade liberalization may affect the price ratio between polluting and clean inputs, thereby changing the optimal mix for producers and consumers. Second, if trade liberalization increases the incomes of consumers, they may want to spend (some of) their additional income on more protection of the environment in order to enjoy better environmental quality. The government can meet this demand by imposing stricter environmental standards on polluting production processes, thereby indirectly affecting the 'technique' of production.[17] Antweiler et al. (2001) put the 'scale, composition and technique' decomposition in a theoretical model framework and provide econometric estimates of their magnitudes in the case of sulfur dioxide concentrations in over forty countries. They found that a one percent increase in per capita GDP due to trade liberalization *reduces* concentrations of sulfur dioxide by one per cent, due to a particularly strong 'technique' effect (due to stricter environmental regulations).

In the same article, Antweiler et al. (2001) presented two opposing theoretical views on the environmental effects of trade liberalization. The first view, the Pollution Haven hypothesis, suggests that trade liberalization will make countries with less stringent environmental regulations dirtier. Unilateral emission restrictions, as in the Kyoto Protocol, increase the comparative advantage of non-abating countries in 'dirty goods' production. Trade liberalization encourages specialization according to comparative advantages and hence encourages the shift of carbon-intensive industries to countries without a carbon dioxide reduction target.

In contrast, the second view, the Factor Endowment hypothesis, suggests that when emissions are concentrated in capital-intensive industries, as is the case for carbon dioxide emissions, then trade liberalization would lead to a further concentration of these industries in relatively capital abundant countries, i.e., the Annex-I countries. Non-Annex-I countries would be encouraged to specialize according to their traditional comparative advantages, i.e., in labor and natural resource-intensive industries that are, on average, not carbon-intensive. To illustrate the Factor Endowment hypothesis, Copeland and Taylor (1994) examined a two-sector, two-country general equilibrium "specific factors" model, in which both sectors in each country use pollution as a factor of production, and

---

[17] To avoid confusion, the concept 'technique' is different from the concepts of 'technological development' or 'technical change'. The 'technique' of production refers to the specific mix of inputs that a firm (or industry, or economy) uses to produce one unit of output. Note that the 'inputs' include emissions of environmental pollutants. The concepts 'technological development' or 'technical change' usually refer to an increase in knowledge so that less inputs are required to produce a given amount of output, or equivalently, that more output can be produced with the same inputs. *Environmental* technical change means that a given amount of output can be produced with less input of emissions of environmental pollutants and a non-increasing amount of other inputs. This study does not address the causes and consequences of technological development or technical change.

each sector uses a specific factor for production, capital or labor, respectively. Capital and pollution are assumed complementary, that is, the capital-intensive industry is also pollution-intensive. One country, the 'North', is assumed to be relatively capital abundant and it has stricter emission controls than the other country, the 'South'. Copeland and Taylor showed that trade increases production of the capital-intensive good in the North and its exports to the South, whereas the South expands its intensive-intensive production. Freer trade reduces pollution in the South, and in the context of climate change, this model suggests that it would be possible, under certain circumstances, for trade liberalization to reduce carbon leakage to non-Annex-I countries.[18]

Antweiler et al. (2001) argued, however, that it cannot be determined on first principles whether the Pollution Haven hypothesis or the Factor Endowment hypothesis will hold. It is therefore a subject for empirical analysis.

Cole et al. (1998) assessed the global impacts on emissions of the trade policy changes that were agreed upon in the Uruguay Round. First, Cole et al. estimated the impacts of the Uruguay Round on the regional output of various industries and on per capita incomes. In a second stage, Cole et al. estimated the effect on emissions (that is, the composition effect), and then use econometrically estimated relationships between per capita income and emissions to estimate a combined scale and technique effect. They found, for industrialized countries, that the composition effect increases the emissions of four traditional air pollutants (nitrogen dioxide, sulfur dioxide, carbon monoxide, and suspended particulate matter). In contrast, in most developing countries (except for Latin America), the composition effect reduces these emissions. Trade liberalization encourages the expansion of energy-intensive industries in industrialized countries, while developing countries specialize in labor-intensive manufactures, such as textiles. In other words, regarding the issue of climate change, the study by Cole et al. suggested that the Factor Endowment hypothesis might dominate the Pollution Haven hypothesis. That is, freer trade might reduce the rate of carbon leakage.

Babiker et al. (1997) assessed, before the conclusion of the Kyoto Protocol, the mutual effects that trade policies and CO_2 reduction policies can have on each other. They used a static 26-region, 13-sector computable general equilibrium model of the global economy that was originally constructed for the analysis of the economic impacts of changes in trade policies (the Uruguay Round), but that was extended with a representation of energy markets and carbon flows. They found that global trade liberalization as agreed in the Uruguay Round, in isolation (without carbon reduction policies), would increase global CO_2 emissions. In combination with unilateral CO_2 emissions reduction of Annex-I countries, however, trade liberalization would reduce global emissions and carbon leakage. Unfortunately, the authors did not explain this result in great detail and the mechanisms underlying their result remain unclear.

Kuik and Gerlagh (2003) assessed the rates of carbon leakage under the Kyoto Protocol with and without freer trade by means of import tariff reductions agreed to in the Uru-

18 It has to be pointed out that the 'pollution' in Copeland and Taylor's model is purely domestic, and that endogenous environmental policies in both countries set optimal emission levels. In contrast, the climate change problem is truly global in nature, and it is not apparent that Copeland and Taylor's results carry over.

guay Round of multilateral trade negotiations. They found that the implementation of these import tariff reductions increases the overall rate of leakage, suggesting that previous studies may structurally have underestimated the rate of carbon leakage under the Kyoto Protocol. They also found, however, that the costs of abating the trade-induced leakage are modest relative to the welfare gains of freer trade. Analysis of the trade-induced carbon leakage showed large differences between leakage caused by reductions of import tariffs on energy goods (high leakage) and by reductions of import tariffs on non-energy goods (low leakage). It also showed large differences in emission responses among developing country regions, with the largest responses by (and therefore the largest leakage to) Brazil and the Middle East and the smallest responses by (and the smallest leakage to) net energy exporting developing countries and the dynamic Asian economies (excluding China) (Kuik and Gerlagh, 2003).

5. Policy implications of carbon leakage

Carbon leakage decreases the net effect of domestic CO_2 emissions reduction on the concentration of greenhouse gases in the atmosphere. It therefore reduces the effectiveness and also the cost-effectiveness of CO_2 reduction policies. If, for example, the Netherlands would, because of the Kyoto Protocol, restrict its CO_2 emissions in 2010 by 13 million tons in comparison to business as usual, a leakage rate of 20 percent would limit the Netherlands' net contribution to global emissions reductions to (13 - 0.2 * 13) = 10.4 million tons. Alternatively, if abatement costs in the Netherlands would be € 20 per ton of CO_2 reduced domestically, it would be 13/10.4 * 20 = € 25 per ton of CO_2 reduced globally.

Whether a leakage rate of 5, 10, 20 or 40 percent or more is acceptable or not is a political judgment. At any leakage rate below 100 percent, Dutch CO_2 reduction policies contribute to global CO_2 reductions, but the higher the rate of leakage, the lower the net effect on global emissions and the higher the cost per ton of net, *global*, CO_2 reduction.

The *first-best policy* to reduce carbon leakage is to increase the size of the group of abating countries.[19] To reduce global carbon leakage, it is not important that additional countries to any international agreement are forced to substantial reductions; it is enough if they agree to any binding target (which might be a zero reduction target with respect to their baseline emissions, i.e., an allowed *increase* of emissions from, say, 1990 levels). Therefore, it would generally improve the effectiveness of the successor of the Kyoto Protocol, if currently non-participating Annex I countries (USA, Australia) and (at least) the larger developing countries (China, India and Brazil) would effectively participate with binding (although not necessarily very restrictive) reduction targets.

Without such broader participation (or in anticipation of such broader participation), it might be worth considering whether domestic or regional (EU) reduction policies could be designed in a manner to reduce carbon leakage. The *second-best policy* would be to implement import and export taxes for the international trade of CO_2-intensive products with non-abating countries. It is commonly *believed* that such a form of trade discrimination would not be allowed under the rules and disciplines of the WTO, but there are precedents by the way of Multilateral Environmental Agreements with (discriminating) trade provisions that have not (yet) been challenged before the WTO. Nevertheless, it

---

[19] Note that what matters is not so much the number of countries, but rather the fraction of global emissions covered. Note also that leakage to some countries (e.g., in Asia) is more likely than leakage to other countries (e.g., in Africa).

appears that the participating countries to the Kyoto Protocol do not actively investigate this second-best policy.[20]

If this *trade* policy would not be feasible, a *third-best policy* would be to differentiate domestic CO_2 reduction policies among sectors. On the basis of their CO_2 intensity and sensitivity to international trade, economic sectors can be classified into 'exposed' and 'sheltered' (Berkhout, Felso, Ferrer-Carbonell et al., 2001). In general, 'sheltered' sectors may be less vulnerable to leakage than 'exposed' sectors (Paltsev, 2001), although differences among sectors and even among firms within these broad classes may be significant.

Any policy that would simply shift a part of the CO_2 reduction burden from the 'exposed' to the 'sheltered' sectors could reduce leakage, but would increase *aggregate* national abatement costs. This increase in costs could be justified from a global cost-effectiveness perspective if the relative increase in costs would be less (in absolute terms) than the resulting reduction in leakage rate.

Most European governments do have special arrangements in their environmental policies for energy-intensive manufacturing industries (Ekins & Speck, 1999). In the Netherlands, these industries are subject to voluntary agreements on energy efficiency and CO_2 emissions, the so-called Benchmarking Covenants. It is generally believed that the targets in these voluntary agreements are not very strict (Kuik & Mulder, 2004; Sijm, 2004a), so that the net costs of CO_2 reduction measures in the energy-intensive manufacturing industries will be small – or even negative (Sijm, 2004a). While such special arrangements could reduce leakage, they also might leave some cost-effective mitigation options in the energy-intensive manufacturing industries untapped, thereby potentially increasing total mitigation costs for the economy. Moreover, lax standards for the energy-intensive manufacturing sectors will not stimulate technological innovation and diffusion of CO_2-efficient production techniques.

On the issue of lax environmental standards, Petrakis and Xepapadeas (2003) argued that environmental policy faced a time inconsistency problem: as long as a firm has not invested in a country, a government has an incentive to keep emission taxes low. However, if the investment has been completed, governments maximizing welfare could have an incentive to increase taxes. In terms of carbon leakage, this would imply that firms, who are aware of this time inconsistency, would rather invest in a non-abating country. One way out of this problem would be to use instruments that pre-commit a government to some level of environmental taxation. Pre-commitment could be an option to limit carbon leakage through international capital mobility.

---

[20] Perhaps it is worth mentioning, as one of the reviewers of an earlier version of this report suggested, that the WTO makes a specific and clear claim that the organization does not deal with environmental protection. The WTO's role is to liberalise trade. Its only dealing with environmental policies is to ensure that these policies do not act as obstacles to trade, and that trade rules do not stand in the way of adequate domestic environmental protection. (http://www.wto.org/english/tratop_e/envir_e/envir_backgrnd_e/c1s3_e.htm). Note also that, if emission reduction policy is based on a carbon or energy tax, border tax adjustments could be allowed, in principle, under WTO law.

The objective of the EU Emissions Trading Scheme (ETS) is to reduce greenhouse gas emissions throughout Europe at the lowest cost. In the first phase (2005-2007), the ETS focuses on the greenhouse gas CO_2 only, and on a number of energy-intensive industries (or rather: 'installations').[21] In principle, the ETS could lead to lower mitigation costs in energy-intensive manufacturing industries, thereby reducing the potential of leakage. In any case, emissions trading is very likely to reduce negative impact on the international competitiveness of energy-intensive industries, and is therefore likely to reduce the risk of international relocation of firms. It is too early to tell, however, how effective the ETS will become, especially in its first phases (Kruger & Pizer, 2004; Sijm, 2004a).

A Dutch advisory commission on emissions trading recently proposed to subject 'exposed' sectors to CO_2-intensity standards, so-called Performance Rate Standards (PSRs) (Commissie CO2-handel, 2002), while 'sheltered' sectors would be subject to an absolute ceiling. For the exposed sectors, the system would not be based on an absolute ceiling (an absolute volume of CO_2 emissions), but on a relative ceiling, i.e., CO_2 emissions per unit of output.[22] Gielen et al. (2002) argued on the basis of a small theoretical model that such a dual system would, on the one hand, provide the right incentive for the exposed sectors to carry out all cost-effective mitigation measures, but would on the other hand, work as an output subsidy for the exposed sectors, so that their output would be less reduced than under an undifferentiated system with an absolute ceiling on national emissions.

While such a dual system might be less efficient from a purely domestic perspective, its propensity to reduce leakage could make it (perhaps) more efficient from a global perspective.[23] The system also provides incentives for technological innovation and diffusion of CO_2-efficient production techniques because the existence of a market for emissions allowances (the sheltered sector), so that any reduction in CO_2 intensity (CO_2 emissions per unit of output) can directly be 'sold' in the form of the sale of emissions allowances. The linkage between a 'relative' (rate-based) sector and an 'absolute' sector poses

---

[21] Combustion plants > 20 MW, oil refineries, coke ovens, ferrous metals, cement clinker, pulp from timber, glass and ceramics (Sijm, 2004a).

[22] The UK Emissions Trading System allows for both absolute and relative (rate-based) targets. Participants to the so-called Climate Change Levy Agreement can opt for relative targets. A complicated mechanism (the 'Gateway') has been set-up to regulate the trade of emission allowances between the 'absolute' and 'relative' sectors (Baron et al., 2002).

[23] Gielen et al. (2002) argued that the costs of meeting a specified domestic target increase under this dual system. Economic instruments, such as a CO_2 tax or emissions trading have two effects: an abatement effect (reducing emissions per unit of output) and an output-substitution effect (reducing the share of CO_2-intensive output in total national output). In comparison with emissions trading under an absolute ceiling, the dual system with an absolute ceiling for the sheltered sectors and relative ceilings for the exposed sectors would produce the same abatement effect but a smaller output-substitution effect. Because emissions trading under an absolute ceiling can, under certain assumptions, lead to a least-cost solution for emissions reduction, the dual system must lead to a higher-cost solution. The 'certain assumptions' are important, however. They include, for instance, the absence of distorting taxes on energy goods in the initial equilibrium. Also, Gielen et al. do not address the magnitude of the cost increase.

some administrative difficulties that have to be solved before such a system can work in practice (Baron & Bygrave, 2002).[24]

An interesting question is whether public support for energy R&D[25] in the energy-intensive manufacturing sectors could lead to increased innovation and technology spill-overs *as well as* reduced leakage. Could energy R&D be a 'double-edged sword'? Technology spillovers is the subject of the accompanying report of Sijm (2004b). To summarize an important point very briefly, there are two alternative views on the relationship between induced technological change and the cost of climate policy. The first view states that climate policy lead to a more rapid technological change and, therefore, to a lower cost of climate policy. The second view refers to the fact that 'climate-related' R&D would absorb funds from the other research areas and, therefore, the cost for the society from the climate policy is going to be higher with induced technological change. This discussion is, however, beyond the scope of this report, and here we will focus on the relationship between R&D and leakage only.[26]

Government support for of innovation can be divided into (at least) three different categories: i) the sponsoring of research and development activities for new technologies, ii) the stimulation of market adoption of new technologies, and iii) investment and exploitation subsidies for adopted new technologies. It is especially the third category of public stimulation of R&D that has a direct effect on marginal costs of production and therefore on international competitiveness and leakage. The first two categories of stimulation could increase competitiveness only in the longer term, when technological innovations might potentially reduce marginal costs. If the mitigation of leakage (also in the short term) would become an important objective of public support for R&D, this might lead to a shift in support from basic R&D (i) to investment and exploitation subsidies (iii). The balance between basic R&D and investment and exploitation subsidies is, however, already heavily tilted towards the latter in Dutch R&D policies. Because climate change is a long-term problem, it would probably be unwise to let short term concerns (competitiveness and leakage) shift attention away from long-term solutions that are likely to require an *increased* research effort by the energy community.[27]

Note that R&D would increase the availability of commercial carbon-extensive technologies not just in countries with emission reduction targets, but in all countries. This has not been extensively studied in the current literature.

In the long run, increased energy R&D and competitiveness can and should go hand in hand. We do not, however, advocate the deployment of R&D instruments to protect competitiveness and to reduce leakage in the short run. In the short to medium term leakage could be reduced through i) increasing country participation in international greenhouse gas mitigation agreements, ii) applying trade measures to the import and export of CO_2-intensive manufactures in the international trade with non-participants to the

---

[24] See also footnote 22 above.

[25] Or, as it is called in recent policy jargon, RD&D (Research, Development and Deployment).

[26] We will also not address the question of the effectiveness of public support for (energy) R&D. This is a crucial question on which very little is known.

[27] The World Energy Council has stated that energy-related R&D expenses are "dangerously low" in comparison to other technology-intensive sectors.

above agreements, and iii) the design and implementation of domestic or European emission reduction schemes that combine an effective 'abatement effect' with a weak 'output-substitution' effect for the most 'exposed' sectors.

However, as most researchers argue that leakage in the short to medium term is primarily caused by changes in relative prices of energy goods (the energy trade channel) and not by industrial relocation, one could also accept an 'unavoidable' rate of leakage in the short to medium term and concentrate on action to avoid leakage by industrial relocation in the longer term. The most obvious course of action would be to stimulate innovation to improve the CO_2–efficiency of exposed sectors in order for them to remain competitive on the world market. In an accompanying report, Sijm (2004b) examines the options and barriers for technological progress in this respect.

6. Conclusions

Carbon leakage refers to the effect that a part of the CO_2 reduction that is achieved by countries that abate CO_2 emissions is offset by an increase in CO_2 emissions in non-abating countries. Carbon leakage can either occur through a combination of changes in relative energy prices, changes in international trade of energy-intensive goods, international reallocation of capital and because of interactions between government climate change policies. The size of carbon leakage because of the implementation of the Kyoto Protocol is still uncertain: it is estimated that between 5 and 20 percent of CO_2 mitigation in Annex I countries will be offset by increases in emissions by non-Annex I countries. Some observers expect a lower rate of leakage because they expect that governments of Annex I countries will take active measures to prevent industrial relocation. A higher rate of leakage may, however, be caused by the non-participation of major Annex I countries such as the U.S. and Australia and non-binding targets for Eastern Europe and the former Soviet Union.

Carbon leakage reduces the global cost-effectiveness of domestic and EU CO_2 mitigation measures. The first-best policy to counteract leakage is increasing country participation in international greenhouse gas mitigation agreements. The second-best policy is applying trade measures to the import and export of CO_2-intensive manufactures in the international trade with non-participants to the above agreements. The third-best policy is to design and implementation of domestic or European emission reduction schemes that combine an effective ‘abatement effect’ with a weak ‘output-substitution’ effect for the most ‘exposed’ sectors. This is no easy task, however. An alternative option would be to accept a certain ‘unavoidable’ rate of leakage in the short to medium term (which is believed to be primarily caused by relative changes in the prices of energy goods) and concentrate on action to avoid leakage through industrial relocation. The EU Emissions Trading Scheme and other international emissions trading initiatives can potentially reduce negative effects on the international competitiveness of energy-intensive industries. In the long run, sustainable innovation in the energy system, competitiveness and leakage reduction should go hand in hand.

References

Albrecht, J. (1998). Environmental policy and the inward investment position of US 'dirty' industries. *Intereconomics*, 33, 186-194.

Annevelink, B., Nabuurs, G.J. & Elbersen, W. (2004). *Case study on the potential for induced technological spillovers in a specific carbon neutral energy supply industry*. Climate Change and Biosphere Research Centre (CCB), Wageningen: UR.

Antweiler, W., Copeland, B.R. & Taylor, M.S. (2001). Is free trade good for the environment? *The American Economic Review*, 91, 877-908.

Armington, P.A. (1969). A theory of demand for products distinguished by place of production. *IMF Staff Papers*, 16, 159-178.

Babiker, M.H. (2001). Subglobal climate-change actions and carbon leakage: the implications of international capital flows. *Energy Economics*, 23, 121-139.

Babiker, M. H. & Jacoby, H. D. (1999). *Developing country effects of Kyoto-type emissions restrictions*. Report No. 53, Cambridge, MA.: MIT Joint program on the Science and Policy of Global Change.

Babiker, M. H., Maskus, K. E. & Rutherford, Th. F. (1997). *Carbon taxes and the global trading system.* Laxenbourg: Paper prepared for presentation at the International Energy Workshop and Energy Modelling Forum Meeting at IIASA.

Babiker, M. H., Reilly, J. M., Mayer, M., Eckhaus, R. S., Wing, I. S. & Hyman, R. C. (2001). *The MIT emissions prediction and policy analysis (EPPA) model: revisions, sensitivities, and comparisons of results*. Report no. 71, Cambridge, MA.: MIT Joint Program on the Science and Policy of Global Change.

Baldwin, R. & Krugman, P. (2000). *Agglomeration, integration and tax harmonization*. CEPR Discussion Paper 2630.

Barker, T. & Johnstone, N. (1998). International competitiveness and carbon taxation. In T. Barker & J. Kohler (Eds.), *International competitiveness and environmental policies*. Cheltenham, UK/Northampton, MA.: Edward Elgar.

Baron, R. & Bygrave, S. (2002). *Towards international emissions trading: design implications for linkages*. Paris: OECD/IEA.

Batra, R., Beladi, H. & Frasca, R. (1998). Environmental pollution and world trade. *Ecological Economics*, 27, 171-182.

Berkhout, P. F., Felso, A., Ferrer-Carbonell, A. & Theeuwes, J. J. M. (2001). *Afbakening afgeschermde sectoren*. SEO paper, Amsterdam: SEO.

Bohringer, Ch. & Rutherford, Th. F. (2000). *Decomposing the cost of Kyoto: A global CGE analysis of multilateral policy impacts*. Crete: Tenth Annual Conference of the European Association of Environmental and Resource Economists.

Bollen, J., Groot, H. L. F. d., Manders, T., Tang, P. J. G., Vollenbergh, H. R. J. & Withagen, C. A. (2002). *Klimaatbeleid en Europese concurrentieposities*. Report no. 24, The Hague: CPB Netherlands Bureau for Economic Policy Analysis.

Bollen, J., Manders, T. & Timmer, H. (2000). *Decomposing carbon leakage*. Melbourne: Third Annual Conference on Global Economic Analysis.

Burniaux, J.-M. (2001). *International trade and investment leakage associated with climate change mitigation*. Fourth Annual Conference on Global Economic Analysis, Volume II, pp. 1-24. West Lafayette, IN: Center for Global Trade Analysis, Purdue University.

Burniaux, J.-M., Martin, J. P., Nicoletti, G. & Oliveira Martins, J. (1992). *GREEN - a multi-sector, multi-region dynamic general equilibrium model for quantifying the costs of curbing CO2 emissions: a technical manual*. Report No.116, Paris: OECD.

Burniaux, J.-M. & Oliveira Martins, J. (2000). *Carbon emission leakage: A general equilibrium view*. ECO/WKP(2000)15, Paris: OECD.

Burniaux, J.-M. & Truong, T. P. (2002). *GTAP-E: an energy-environmental version of the GTAP model*. Technical paper no. 16, West Lafayette, IN: Purdue University.

Cole, M.A., Rayner, A.J. & Bates, J.M. (1998). Trade liberalisation and the environment: The case of the Uruguay Round. *The World Economy*, 21, 337-347.

Commissie CO2-handel. (2002). *Handelen voor een beter milieu* (Trading for a better environment). De Meern: KPMG Milieu.

Copeland, B. R. & Taylor, M. S. (2003). *Free trade and global warming: A trade theory view of the Kyoto Protocol*. Revised version. http://econ.ucalgary.ca/fac-files/st/KyotoMarch13.pdf

Copeland, B.R. & Taylor, S.M. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, 109, 755-787.

CPB. (1999). *WorldScan: the core version*. The Hague: CPB Netherlands Bureau for Economic Policy Analysis.

Daly, H. (1993). The perils of free trade. *Scientific American*, 24-29.

Dean, J. M. (1992). Trade and the environment: a survey of the literature. In P. Low (Ed.), *International trade and the environment* (pp. 15-28).

Dean, J. M. (2002). *International trade and the environment*. Aldershot UK: Ashgate Publishing.

Elbers, C. & Withagen, C. (2004). Environmental policy, population dynamics and agglomeration. *Contributions to Economic Analysis & Policy*, 3, 1-21

Ekins, P. & Speck, S. (1999). Competitiveness and exemptions from environmental taxes in Europe. *Environmental and Resource Economics*, 13, 369-396.

Fujita, M., Krugman, P. & Venables, A. (1999). *The Spatial Economy: cities, regions and international trade*, Cambridge: the MIT Press, 367 p.

Gielen, A., Koutstaal, P. & Vollebergh, H. R. J. (2002). *Comparing emission trading with absolute and relative targets.* London: Paper presented to the second CATEP Workshop.

Gielen, D. & Karbuz, S. (2003). *Challenges in energy and environment modelling: a materials perspective*. EET/2003/05, Paris: OECD/IEA.

Gordon, R.H. & Bovenberg, A.L. (1996). Why is capital so immobile internationally? Possible explanations and implications for capital income taxation. *The American Economic Review*, 86, 1057-1075.

Grubb, M., Hope, C. & Fouquet, R. (2002). Climatic implications of the Kyoto Protocol: the contribution of international spillover. *Climatic Change*, 54, 11-28.

Gürtzen, N. & Rauscher, M. (2000). Environmental policy, intra-industry trade and transfrontier pollution. *Environmental and Resource Economics*, 17, 59-71.

Hertel, Th. W. (1997). *Global trade analysis: modeling and applications*. Cambridge: Cambridge University Press.

Hertel, Th. W., Hummels, D., Ivanic, M. & Keeney, R. (2003). *How confident can we be in CGE-based assessments of free trade agreements?*. GTAP Working Paper No. 26, West Lafayette: GTAP Purdue University.

Herzberg, V. & Minne, B. (1992). *Nederlandse industrie en regulerende energieheffing*. Report No. 90, The Hague: CPB Netherlands Bureau for Economic Policy Analysis.

Hoel, M. (1996). Should a carbon tax be differentiated across sectors? *Journal of Public Economics*, 59, 17-32.

IPCC (2001). *Climate Change 2001: Mitigation*. Cambridge: Cambridge University Press.

Jeppesen T. & Folmer, H. (2001). The confusing relationship between environmental policy and location behaviour of firms: a methodological review of selected case studies. *Annals of Regional Science*, 35, 523-546.

Jeppesen, T., List, J. & Folmer, H. (2002). Environmental regulations and new plant location decisions: evidence from a meta-analysis. *Journal of Regional Science*, 42, 19-49.

Kruger, J. & Pizer, W. A. (2004). *The EU Emissions Trading Directive: opportunities and potential pitfalls*. Discussion paper 04-24, Washington, D.C.: Resources for the Future.

Krugman, P. (2001). *Ricardo's difficult idea*. http://web.mit.edu/krugman/www/ricardo.htm.

Krugman, P. & Obstfeld, M. (2000). *International economics: theory and policy*. (Fifth edition ed.). Reading: Addison-Wesley Publishing Company.

Kuik, O.J. & Gerlagh, R. (2003). Trade liberalization and carbon leakage. *The Energy Journal*, 24, 97-120.

Kuik, O.J. & Mulder, M. (2004). Emissions trading and competitiveness: pros and cons of relative and absolute schemes. *Energy Policy*, 32, 737-745.

Lako, P. (2004): *Spillover effects from wind power, case study in the framework of 'Spillover study'*, Petten/Amsterdam: Energy Research Centre of the Netherlands (ECN).

Lejour, A. & Manders, T. (1999). *How carbon-proof is Kyoto? Carbon leakage and hot air*. CPB report 99/4, The Hague: CPB Netherlands Bureau for Economic Policy Analysis.

Light, M. K., Kolstad, C. D. & Rutherford, Th. F. (1999). *Coal markets and the Kyoto Protocol*. Boulder, CO: University of Colorado.

List, J., McHone W. W. & Millimet, D.L. (2003). Effects of air quality regulation on the destination choice of relocating plants. *Oxford Economic Papers*, 55, 657-678.

Liu, J., Arndt, C. & Hertel, Th. W. (2001). *Parameter estimation and measures of fit in a global, general equilibrium model*. Purdue, West Lafayette, IN.: Paper submitted to the Fourth Annual Conference on Global Economic Analysis.

Manne, A.S. & Richels,R.G. (2000). MERGE [Computer Software]

Markusen, J.R. (1975). International externalities and optimal tax structures. *Journal of International Economics,* 5, 15-29.

Markusen, J. R., Melvin, J. R., Kaempfer, W. H. & Maskus, K. E. (1995). *International trade*. New York: McGraw-Hill Inc.

McKibbin, W. J., Ross, M.T., Shackleton, R. & Wilcoxen, P.J. (1999). Emissions trading, capital flows and the Kyoto Protocol. *The Energy Journal*, (Special issue on the Kyoto Protocol), 287-333.

McKibbin, W. J. & Wilcoxen, P. J. (1995). *The theoretical and empirical structure of the G-Cubed model*. Discussion Papers in International Economics No. 118. Washington D.C.: Brookings.

Mundell, R. (1957). International trade and factor mobility. *American Economic Review*, 67, 321-335.

OECD. (1999). *Action against climate change.* The Kyoto Protocol and beyond. Paris: OECD.

Oikonomou, V., Patel, M. & Worrell, E. (2004): *Does climate policies lead to relocation with adverse effects for GHG emissions or not? A first assessment of the spillovers of climate policy for energy-intensive industry*. Utrecht: Report NW&S-E-2004-14, Department of Science, Technology and Society (STS), Copernicus Institute, Utrecht University.

Paltsev, S.V. (2001). The Kyoto Protocol: regional and sectoral contributions to the carbon leakage. *The Energy Journal*, 22, 53-79.

Pethig, R. (1976). Pollution, welfare, and environmental policy in the theory of comparative advantage. *Journal of Environmental Economics and Management*, 2, 160-169.

Petrakis, E. & Xepapadeas, A. (2003). Location decisions of a polluting firm and the time consistency of environmental policy. *Resource and Energy Economics* 25, 197-214.

Rauscher, M. (1997). *International Trade, Factor Movements, and the Environment*. Oxford: Clarendon Press.

Ricardo, D. (1821). *On the principles of political economy and taxation*. (Third edition ed.).

Rutherford, Th. F. (1998). *GTAPinGAMS: the dataset and static model*. Boulder: University of Colorado, Department of Economics.

Sijm, J. (2004a). Implementing emissions trading in the EU: how to optimise its economic benefits? In ECN (Ed.), *Dutch energy policies from a European perspective: Major developments in 2003* (pp. 33-44). Petten: Publication Services ECN.

Sijm, J. (2004b). Induced technological change and spillovers in climate policy modelling: an assessment. Amsterdam: ECN.

Smith, A. (1776). *An inquiry into the nature and causes of the wealth of nations*. London: Methuen and Co., Ltd., ed. Edwin Cannan, 1904. Fifth edition.

Springer, K. (2000). *Do we have to consider international capital mobility in trade models?* Kiel Working Paper No. 964, Kiel: Kiel Institute of World Economics.

Ulph, A. (1997). Environmental policy and international trade: a survey of recent economic analysis. In H. Folmer & T. Tietenberg (Eds.), *International Yearbook of Environmental and Resource Economics.* Cheltenham: Edward Elgar.

Wang, Z. K. & Winters, L. A. (2001). Carbon taxes and industrial location: evidence from the multinationals literature. In A. Ulph (Ed.), *Environmental Policy, International Agreements, and International Trade* (pp. 135-151). Oxford: Oxford University Press.