June 18, 2001 (first version)

International Trade and Investment Leakage Associated with Climate Change Mitigation

Jean-Marc Burniaux, Purdue University and OECD[1].

1. Introduction

Against the background of increasing scientific consensus about the influence of manmade emissions of greenhouse gases (GHGs) on Earth climate, a number of industrialized countries signed the Kyoto Protocol in December 1997 committing these countries to reduce their emissions of the main GHGs. Such unilateral action by a group of countries (so-called Annex 1 countries[2]) has raised serious concerns about its environmental effectiveness and its costs to acting countries. Relatively high abatement costs in Annex 1 countries are feared to undermine the competitiveness of energy-intensive industries on international markets. This could in turn reduce the already small impact of the Protocol on world emissions, as emissions in countries that have not signed the Protocol would increase as a result of the mitigation effort undertaken by the Annex 1 counties, an effect that has been widely referred to as "carbon leakages".

Although the evidence of large carbon leakage has not yet been demonstrated, their potential existence and their associated costs seemingly provided an underlying justification – or an excuse – for the unilateral withdrawal of the US from the Kyoto Protocol on March 2001[3]. This demonstrates that trade competitiveness issues and the related possibility of carbon leakage are central to the design of a climate policy agreement and will remain so during any further renegotiation of the Kyoto Protocol, unless a global agreement implying quantitative constraints on emissions from all countries in the world can be achieved.

Many ambiguities contribute to obscure the policy debate about carbon leakages. First, environmental effectiveness and economic costs should be considered separately.

[1] The author wrote this article when he was on sabbatical leave at the Center for Global Trade Analysis, Purdue University. The views expressed in this article do not necessarily reflect those of the OECD and its Member countries.

2 .Referred to as Annex 1 countries in the discussion even though the Protocol lists them in annex B.

[3] Transcripts from the White House repeatedly report that "the huge costs that are involved are disproportionate to the benefits, particularly when most of the world is exempt" as the main justification of the decision taken by G.W Bush to withdrawn from the Protocol.
(see http://www.whitehouse.gov/news/briefings/20010328.html).

Although economic costs tend to be higher in the presence of higher leakage (Bernard and Vielle, 2000), a relatively modest leakage level should not hide the fact that some producers in Annex 1 countries – especially in energy-intensive industries - would face serious competitiveness problems and related losses of output and employment (Manne and Richels, 1998). Second, and more important, most of the leakage is not related to the loss of competitiveness of energy intensive sectors. As this paper makes clear, other factors – such as the supply reaction of fossil fuels producers, the degree of technological flexibility and the investors behavior are more influential.

Thus assessing the potential of carbon leakage is central in the evaluation of any unilateral mitigation policy by a group of countries as well as its chances of being extended worldwide[4]. However, it is striking that existing global models have failed so far to provide a coherent view on the magnitude and the regional distribution of the carbon leakages that could emerge following the implementation of emission abatements by a group of industrialized countries. This paper contributes filling this gap by discussing the main determinants of leakages and quantifying their magnitude. In particular, it focuses more narrowly on a leakage source that has deserved relatively little attention in the literature so far, namely leakages that are generated by the international reallocation of investment.

2. Mechanisms underlying carbon leakages

Carbon leakages can be generated through different mechanisms. To simplify, two main general equilibrium channels can be distinguished: *energy* and *non-energy* markets.

In the channel that operates via non-energy markets, carbon abatement imposed unilaterally raises production costs affecting the competitiveness of energy-intensive industries. These industries can lose market shares in the international markets in favor of industries located in countries that do not reduce their emissions; this causes a corresponding shift in the production of energy-intensive goods at the world level. The trade substitution elasticities (the so-called Armington elasticities) usually represent the intensity by which this mechanism operates. The larger these elasticities, the larger the effect of prices on market shares.

Another non-energy channel is through the reallocation of foreign direct investments to non-participating countries. The leakage generated through this channel is dynamic by nature: as additional investments in non-participating countries result into higher economic growth, GHGs emissions increase over the future. Key parameters here are the degree of international mobility of capital and the reaction of investors to expected rates

[4] The literature based on game theory shows that higher leakage rates reduces the size of a stable, self-enforcing coalition to reduce emissions as it increases the free-riding incentive (see, for instance, Carraro,1998; Botteon and Carraro, 1998).

of return. The contribution of this paper is to quantify the importance of this channel in comparison to the others.

The channel related to energy markets operates in the following way. When a unilateral carbon abatement occurs in a large country group, the reduction in world demand would cause a fall of the international price of the most carbon-intensive fossil fuels, thus increasing energy demand and carbon emissions in the non-participating countries. But, the structure of the international energy markets matters for the size and scope of this effect.

Indeed, while oil can be considered a fairly homogenous good there is more uncertainty about the degree of integration of the world coal market.[5] There are many coal varieties and secondary energy producers may not shift easily from one to another source of supply. Perhaps even more important than the structure of the international carbon market, the supply response of fossil-fuel producers will also be determinant. Indeed, the potential for reducing world carbon emissions ultimately relies on the decision by the carbon producers to keep extracting carbon-based energy or to leave it in the ground. The key parameters characterizing the behavior of carbon producers are the supply elasticities for coal, oil and natural gas. Given that coal is the most carbon-intensive fuel, the supply elasticity of coal can be expected to be influential for the size of carbon leakages.

There are a number of other factors that may also prove important. Firstly, in the specific context of the Kyoto Protocol, the existence of so-called "hot air" in the Russian Federation and Ukraine implies that emissions in these two countries are not subject to any binding constraint. This raises the possibility of carbon leakages within the group of the Annex 1 countries. Secondly, after the implementation of the Kyoto Protocol, a fall of the international price of oil relative to the coal price would lead to a shift of energy demand from coal to oil. This would induce a fall of the carbon intensity in some large coal consuming countries, like China (inducing possible so-called "negative leakages"). These negative leakages are most likely to appear if the supply elasticity of oil is small while the supply of coal is elastic. Finally, the size of the leakages can also depend on the loss of income in energy-exporting economies, reducing their domestic demand and carbon emissions (hence also creating negative leakages). But this factor is likely to be of a second order influence over the time horizon of the first budget period of the Protocol.

3. Quantitative estimates of carbon leakages : a (non-exhaustive) literature survey

5. High transportation costs, lack of infrastructure and other technical aspects have so far contributed to restrict coal trading to a fraction of the world coal production, although Light, Light and Rutherford (1999) argue that the international coal market is actually more integrated than it appears.

The above discussion of the mechanisms that contribute to carbon leakage suggest that these are the result of complex interactions between energy and non-energy markets. In the absence of any direct empirical evidence, an option is to rely on model simulations. Global General Equilibrium (GE) models have long been used in order to assess the magnitude of carbon leakages. By far the most striking evidence from these estimates is how divergent they are. Table 1 reviews some recent estimates of the leakage associated to the implementation of the Kyoto Protocol based on various existing models. The "leakage rate" is defined here as the ratio of the additional emissions in the non-Annex 1 countries to the emission reduction achieved in Annex 1 countries. The estimates range from around 20 per cent in WorldScan, MERGE and Rutherford's[6] models to the lower bound estimates of 2 to 5 per cent provided by the GREEN, G-cubed and EPPA-MIT models**.**

So far, the literature has shed some light on some factors underlying these divergences. Using the OECD GREEN model, Oliveira Martins (1995) presented sensitivity analysis showing that the values of the energy supply elasticities appear more influential in determining leakage rates than the elasticity of substitution in the world markets for energy-intensive goods. The analysis also points to the possibility of *negative* leakage effects, i.e. a possible reduction of emissions in some non-participating countries. This effect is due to the fall of the international relative price of oil vis-à-vis coal, which induces a shift towards less carbon-intensive energy consumption in the non-participating countries. These negative leakages explain part of the low net leakage rate in a model like GREEN. Also using a sensitivity analysis approach, Bollen *et al.* (1999) show that an important factor determining the magnitude of carbon leakages are the substitution possibilities in the production function. Finally, Light *et al.* (1999) assert that the structure of the international coal market is critical to understand the leakage mechanisms; if the degree of integration of the coal market is understated this necessarily leads to underestimation of the carbon leakages.

However, drawing robust and consistent conclusions in this area is made difficult by the need to take into account the interactions between different parameters over a wide range of values. Overlooking this *multidimensionality* aspect can lead to false, or at least incomplete, interpretation of the factors and the mechanisms underlying carbon leakages. Using a simple, static CGE model, Burniaux and Oliveira-Martins (1999) make an extensive multidimensional sensitivity analysis in order to indentify which of the key parameters are the most influential in determining the rate of carbon leakage. The main conclusions of their study are :

- The non-energy trade channel (as determined by the value of the so-called Armington elasticities is less influential in determining leakages than often thought. In other words, the leakage rate is not very sensitive to the degree of trade substitution on the non-energy markets.
- By far the most influential parameter is the supply elasticity of carbon. Elasticity values above 3 yields small and relatively stable leakage rates.

6 . The paper by Light *et al*. (1999) quoted in Table 1 is based on a model developed by Thomas Rutherford (University of Colorado, Boulder).

When the carbon supply elasticity falls below 3, leakage rises very substantially (to rates of up to around 40 per cent). As an extreme case, which illustrates the intuition behind this result, a perfectly inelastic supply of carbon would make impossible to reduce world emissions of carbon and the leakage rate of any unilateral abatement would, by definition, equal 100 per cent. With this respect, the value of the supply elasticity of coal is critical in determining the amount of leakage.

- With regards to the structure of the coal market, the supply elasticity of coal is more influential than the degree of substitution on the international coal market. A relatively high value of the supply elasticity of coal will always generates a low leakage rate whatever the imputed degree of substitution on the international coal market. The degree of integration of the international coal market only matters if the value of the supply elasticity of coal is relatively low. This again highlights the importance of the behavior of the coal producers.
- Finally, the degree of substitution in the production function also matters for the size of the carbon leakage, a fact that has attracted relatively little attention so far in the analytical literature. Higher factor substitution yields larger leakage as it amplifies the reduction of the carbon demand and the increase of demands for other factors, including less carbon-intensive fuels (such as oil and gas) and carbon-free energy sources. In this context, the value of the supply elasticities of oil and gas, the degree of depletion of oil and gas reserves as well as the existence and availability of alternative carbon-free energy sources are critical factors.

According with these results, the focus about carbon leakages should be shifted from trade competitiveness towards energy supply. Ultimately, if energy is in infinite supply, any abatement strategy undertaken by a group of industrialized countries would result into a shift from carbon to non-carbon energy sources with little or no changes of the relative energy prices and therefore no substantial leakage.

However, this analysis leaves aside a channel of leakage that has been little discussed in the literature so far: the international capital mobility related to the reallocation of investment and the resulting effects on growth and emissions. With a fairly elaborated description of the international capital markets, the G-Cubed model reports that capital reallocation in the context of the Kyoto Protocol has little impact on leakage as most of this reallocation takes place among Annex 1 countries rather than towards non-Annex 1 countries (McKibbin et al., 1999). Similarly, Babiker (2001) shows that assuming perfect capital mobility does not affect the carbon leakage significantly.

This analysis aims at quantifying the impact of international capital mobility on leakage by using a dynamic GE model with a fairly developed treatment of the investors decision. Its main outcome is in line with previous studies : it confirms that, under "reasonable" assumptions, the carbon leakage associated with the implementation of the Kyoto Protocol should be modest and not significantly affected by the amount of investment reallocation. But extensive sensitivity analysis also shows that this result is less robust than thought at first glance. In particular, the existence of investment reallocation may become much more influential under certain circumstances related to different types of investors expectations, different levels of interfuel substitution, a longer time horizon and the existence or not of alternative carbon-free energy sources (called "backstops" energies).

4. GDYN-E : a dynamic GE model to simulate GHGs policies.

The model that is used to estimate the carbon leakage associated to the implementation of the Protocol is the GDYN-E model developed at the Center for Global Trade Analysis. It is an extension of the Dynamic GTAP model (Ianchovichina and McDougall, 2001). It has been extended by incorporating some of the basic features that are needed in order to assess policies aimed at stabilizing climate[7]. In particular, it is disaggregated in order to identify the major energy sources and has a production structure that allows to analyze the technological adjustment to abatements. On the other hand, this model offers a disequilibrium treatment of international capital mobility based on the new investment theory that makes it appropriate to analyze the investment response to unilateral abatement strategies.

4.1. Model structure

The current version of the model has a worldwide coverage with eight countries/regions and nine producing sectors (see Table 2). It is recursively dynamic and is based on the 1995 version of the GTAP database. As in most "top-down" models, the production structure is characterized by constant returns to scale and the available technology is represented by assuming that the decision of producers is separated into several stages. These stages are specified by using nested Constant Elasticity of Substitution (CES) functions.

The nesting used in GDYN-E is similar to the one used in other models, such like GTAP-E (Truong, 2000) or GREEN (Lee, Oliveira-Martins and van der Mensbrugghe, 1994). First, producers are assumed to choose the mix between intermediate non-energy inputs and a composite input including all primary factors (labor, capital and a so-called fixed factor) and energy (see Figure 1). Second comes the allocation of this composite input between labor and a composite capital/fixed factor/energy inputs. Third, the mix between energy and the capital/fixed factor bundle is chosen. Fourth, the later input is split assuming perfect complementarity between capital and the fixed factor.

[7] The version of the model that is used here is preliminary as the extension of the model is an ongoing work.

The energy bundle is in turn divided into the various energy sources. The first level is the allocation of the total energy demand into an electric component and a non-electric component. The non-electric component is then divided into coal and a residual energy input grouping oil, gas and refined petroleum products. The bottom level of the CES nesting concerns the substitution between oil, natural gas and refine petroleum products. The production structure allows to incorporate, though in an aggregate way, some of the features that characterize the choice of energy technologies, such as a certain degree of complementarity between capital and energy and separability in the decision to use coal and electricity power. However, the current version of the model does not incorporate some of the features that can be found in similar models (for instance, the GREEN model) such as a dynamic capital vintage structure, backstop energy sources, depletion of fossil fuels reserves. Also, the model only considers the manmade emissions of CO_2 (expressed in tons of carbon equivalent) and not the emissions of the other greenhouse gases (methane, nitrous oxide, …). All commodities in GDYN-E are differentiated by country/region of origin using the well-known Armington specification. The values of the most important parameters of GDYN-E are reported on Table 3.

4.2. The investment decision

An innovative feature of GDYN-E is the treatment of investors decisions and capital mobility (see Ianchovichina and McDougall, 2001 for a detailed description). First, the model identifies agent's financial assets and liabilities and the associated income receipts and payments, though in a simplified way. The model only considers one single asset type: equity. Thus, there is no debt and money. Due to data limitations, the model identifies a representative regional household in each country/region that holds equity in local firms and in a so-called global trust. In turn, the global trust holds equity in firms in all regions[8]. The regional households receive incomes from the equity they hold in the local firms and in the global trust; the global trust receive incomes from the equity it holds in country/region firms. These income flows are endogenously determined. The net income flow between incomes paid by regional firms to the global trust and incomes paid by the global trust to regional households is a component that endogenously determined the current account balance of each country/region[9].

The central element of the investment behavior in GDYN-E is the perception of investors that the higher the level of the capital stock at any given time, the lower the rate of return at that time. Thus, the profit maximizing behavior of investors in GDYN-E can be represented by a downward sloping relationship between the rate of return and the capital stock (see Figure 2). In addition, investors are assumed to react to expected rather than actual rates of return. Thus the downward sloping schedule E on Figure 2 relates to investors expectations. At any time, an observed level of capital stock (K) relates to an expected rate of return (Exp).

[8] The "global trust" as a financial intermediary is a fiction in order to avoid estimating bilateral data on foreign assets and liabilities.
[9] The other component being the difference between regional investment and saving.

In a world of perfectly mobile capital, profit-maximizing investors would reallocate their investment instantly so that the rates of return across countries would remain equal. In GDYN-E, this adjustment towards this equilibrium uniform rate of return – called the target rate – takes time. For instance, in Figure 2, where the target rate is above the expected rate of return, investors would be expected to reduce their investment in the corresponding country, as they find more profitable opportunities in other countries. This occurs gradually, as investors move upward along their expected investment schedule.

The expected rate of return differs from the actual one and investors take advantage from their past expectation errors to correct their expectations. In Figure 2, the actual rate is well above the expected rate. Adaptive corrections of the expectation implies an upward shift of the expected schedule (E) towards the actual schedule (A). But again, in GDYN-E, this correction occurs gradually with a lag.

Finally, over the long run, GDYN-E converges towards a stable equilibrium where the actual and expected investment schedules coincide and the target, expected and actual rates of return are equal and constant. This is introduced through a normal rate of growth in the capital stock, defined as the rate of growth that corresponds to a constant rate of return. However, there is no reason why this underlying normal rate of growth should be constant. For instance, a tax reform may result into a higher (or a lower) normal rate of growth depending on how optimal is the new tax structure. Investors also adjust their expectations about the underlying normal rate of growth in a way that is model-consistent. For instance, in Figure 2, if the actual rate of return is still rising given the current level of the capital stock, investors may start thinking that the normal rate of growth (i.e. the rate at which the rate of return remains constant) is actually higher than they thought. This implies an additional outward shift of their expected investment schedule in the direction of the actual schedule.

All three mechanisms combine in determining the level of investment in each country.

5. Investment responses to emission abatements : an analytical view

Before discussing the results, it is worth discussing how abatements of CO2 emissions by a typical Annex 1 country will affect the above described mechanisms of the investment decision.

5.1. The case of an Annex 1 country.

Figure 3 illustrates the investment response to abatement in a typical Annex 1 country, starting from the long run equilibrium situation (with both actual and expected investment schedules coinciding and actual, expected and target rates of return equal). To the extent that capital and energy are more or less complementary, the imposition of an emission constraint will reduce the actual rate of return of capital. In the meantime, the fact that major industrialized countries undertake emission reductions together will induce a worldwide excess supply of capital, causing the long-run equilibrium target rate to fall. In Figure 3, the actual and target rates are assumed for simplicity to fall by the same amount and the actual schedule moves downward. As investors gradually revise their expectation of the rate of return downward, the expected schedule also shifts downward. But the major response comes from an adjustment of the normal rate of growth of capital. As the actual rate of return keeps falling despite the reduction of the capital stock, investors speculate that the implementation of emission reductions permanently reduces the normal rate of growth of capital and they reduce their investment accordingly. Thus the investors expected schedule in Figure 3 moves inward up to the point where a new long-term equilibrium is reached. The net outcome for a typical Annex 1 country is a reduction of the level of investment.

5.2. The case of a non-Annex 1 country.

Figure 4 shows the investment response in a non-Annex 1 country. The fall of the rate of return in Annex 1 countries yields opportunities for profitable investments in non-Annex1 countries. In the meantime, as the long-term equilibrium target rate falls, investors form expectations that the rate of return will decline in the future. Thus, investment in non-Annex 1 countries increases as investors gradually move downward and rightward along their expected investment schedule (Figure 4). Investors also realize that a better competitiveness relative to Annex 1 firms and lower energy prices (due to the emission restrictions undertaken in Annex 1 countries) may result into a higher normal growth rate of capital and this also encourages them to invest more[10]. Accordingly, the expected schedule moves outward, as the actual schedule does it. The net outcome for a typical non-Annex1 country is an increase of the level of investment.

In a simplified two region world (Annex 1 and non-Annex1), the investment response to emission abatement in the non-Annex 1 country implies a reallocation of investment towards the non-Annex 1 country. The resulting impact on the long-term economic growth implies higher emissions in the non-Annex 1 country and, thus, a higher amount of leakage. Things are more complicated in a multi-regional model because Annex 1 countries are not homogenous. In particular, the Protocol of Kyoto implies that some countries are facing sharp emission reductions (such like the US and the European Union) while other countries are likely to meet their Kyoto commitment even if they do nothing to reduce their emissions (such like the Former Soviet Union). In this context, an important amount of investment reallocation should take place among Annex 1 countries, as the results described in the next section illustrate.

[10] The fact that the rate of return does not decline despite a higher level of capital stock implies that the actual schedule has shifted rightward and that the normal rate of growth of capital (i.e. the rate that is consistent with a constant rate of return) has increased. Investors incorporate this information into their expectation in a model-consistent way.

6. Leakage and investment reallocation in the Kyoto Protocol

6.1. Leakage rates in the context of the Kyoto Protocol: a model comparison

The above discussion suggests that the likely investment response to unilateral emission reductions is redistribution from participating to non-participating countries but that the magnitude of this redistribution cannot easily be predicted, in part because some reallocation will take place among Annex1 countries. The net outcome for the leakage rate is ultimately an empirical issue. The Figure 5 reports the leakage rate estimated in GDYN-E in a scenario in which the Annex 1 countries meet their Kyoto requirements individually – i.e. without the use of any kind of emission trading – by 2010 and then keep their emissions constant hereafter (hereafter referred to as “Kyoto for ever”). To put these results into perspective, these leakage rates are compared with the corresponding estimated rates from the GREEN model. Both models have been calibrated using similar parameter values. The GREEN model incorporates features that are not present in GDYN-E: such as backstops technologies, non-renewable reserves of oil and gas and a capital vintage structure of production. But, unlike GDYN-E, GREEN has a very simplified treatment of international capital markets, with investment treated as a residue and the net flow of capital in each country/region being exogenous and constant over time (i.e. implying no capital mobility). Thus comparing the leakage rates from these two models should help answering the question of whether a more realistic treatment of international capital mobility matters in estimating the leakage rate.

The Figure 5 provides an answer to this question. Up to the time horizon of the first commitment period of the Protocol – i.e. 2010 – the answer unambiguously is that international capital mobility does not matter for the rate of leakage. Both models predict modest leakage rates around 4 per cent of the total emission reduction achieved by the Annex 1 countries[11]. The fact that both models generate the same range of leakage is not a surprise, given that they are both calibrated on the same parameter values implying, in particular, the important assumption that coal supply is almost perfectly elastic while the supply of crude oil is much less elastic (see below). This again stresses the fact that, beyond differences of model structure, it is the supply behavior of fossil fuel producers that really matters for the leakage, at least over the medium term.

Over the longer run, however, this outcome needs some qualification. In GREEN, leakage rates beyond 2010 gradually declines. Again, this mainly reflects important

[11] This estimate does not incorporate the leakage in the former Soviet Union. Because the Kyoto constraint is not binding, emissions in the former Soviet Union may increase as a result of the implementation of the Protocol, assuming that there is no emission trading.

changes in the supply of carbon. In accordance with EMF guidelines, the GREEN model makes the important assumption that carbon-free energy sources become available in infinite supply at a given price after 2010. This substantially reduces the marginal cost of maintaining the Kyoto levels of emissions constant after 2010 as well as the associated leakage rates[12]. On contrary, there is no backstop energy sources in the GDYN-E model. As a result, GDYN-E reports leakage rates to gradually increase beyond 2010 up to 13 per cent in 2030, though not a very large rate but still a significant one. As the following section makes clear, this increase mainly reflects the dynamic effects of the worldwide investment reallocation caused by the emission abatements undertaken in Annex 1 countries.

6.2. Leakage decomposition

The reason behind leakage is better assessed by running two intermediate scenarios that can be used to decompose the leakage into the channels identified above. The first scenario (referred to as “fixed prices Kyoto”) has the same features than the “Kyoto for ever” scenario described above, except that the prices (excluding taxes) of the primary fossil fuels (coal, crude oil and natural gas) are kept constant at the same level an in the baseline scenario. The difference between the “fixed prices Kyoto” and the “Kyoto for ever” scenarios allows identifying the amount of leakage that is channeled through the changes of the international energy prices. The second scenario (referred to as “fixed prices, fixed K Kyoto”) assumes that both the prices of the primary fossil fuels and the capital stock in each region/country are kept constant at the same level as in the baseline scenario. The difference between this “fixed prices, fixed K Kyoto” and the “fixed prices Kyoto” scenarios allows to quantify the impact of the change of the capital stock in each region/country, as a result mainly of the worldwide investment reallocation. Finally, the only difference between the “fixed prices, fixed K Kyoto” scenario and the baseline scenario is that the economic structure in both Annex 1 and non-Annex 1 countries is distorted due to the implementation of the emissions reductions in Annex 1 countries. This allows to identify the third component, i.e. the amount of leakage that is generated through a shift of the producing structure towards more carbon-intensive industries.

The Figure 6 shows the decomposition of the leakage in GDYN-E from 2005 to 2030. Up to 2010 – i.e. the first commitment period of the Protocol – the change of the energy prices is the major source of leakage with the investment reallocation effect coming second. Beyond 2010, the dynamic consequence of the investment reallocation gradually becomes the major source of leakage[13].

Surprisingly, the structural component is negative. One would expect the loss of competitiveness of energy-intensive industries in Annex 1 countries to contribute to the expansion of these industries in non-Annex 1 countries, leading to additional leakage. But this effect is more than offset by the expansion of the capital producing industry in non-

[12] A similar result is reported in Babiker, 2001.
[13] Taking in mind that GDYN-E has no backstops.

Annex 1 countries, as a result of the investment reallocation[14]. Thus, non-Annex 1 economies become relatively less carbon-intensive, once the impact of the changes of the primary energy prices is taken out.

6.3. Emission trading and carbon leakage

The above results suggest that, under certain circumstances, the dynamic effects associated with investors responses may affect the amount of carbon leakage. The implication is that the policy design of any unilateral action to reduce emissions, to the extent that it affects investors decisions, will matter for the rate of leakage. For instance, the fact that Annex 1 countries are allowed to trade emission rights among themselves[15] will modify the patterns of investment reallocation.

Model simulations have indicated that emission trading is likely to reduce the amount of leakage. For instance, in the GREEN model, assuming an unrestricted trading of emission rights among Annex 1 countries cuts the leakage rate by half (see Table 1). The explanation is that trading shifts the burden of the abatements away from petroleum products to coal in the Former Soviet Union. As the supply of coal is assumed to be fairly elastic, the outcome is a smaller fall of the carbon price worldwide in reaction to the Annex 1 abatements, hence a lower carbon leakage. Trade-offs between investment reallocation and emissions trading might change this outcome, for instance by increasing the proportion of net investment that flows out of Annex 1 countries.

However, results from GDYN-E show little impact from the investment reallocation: the leakage rate in 2010 falls from 5 per cent with no emission trading to 2.6 % per cent with an unrestricted emission trading among Annex 1 countries. The Figure 7 shows that, in 2010, the total amount of net investment that is reallocated worldwide accounts for 160 billions of 1995 USD assuming no emission trading, most of it originating from the US. About half of this net investment surplus benefits the non-Annex 1 countries[16]. With emission trading, the total net investment surplus from non-Annex1 countries (mainly the US and the "Eastern Europe + Former Soviet Union" region) is substantially smaller while its distribution between Annex 1 and non-Annex 1 countries remains almost the same. Thus non-Annex1 countries benefit from a smaller investment inflow in absolute terms. If any, the impact of international capital mobility in the context of emission trading is to reduce the amount of carbon leakage.

---

[14] And given that the capital producing sectors in non-Annex1 countries are relatively less energy-intensive according with the GTAP data.

[15] The Protocol makes provision for two specific instruments – Emission Trading and the Joint Implementation – that should allow Annex 1 countries to reallocate their commitments among themselves.

[16] Surprisingly, most of the investment that is reallocated among Annex 1 countries benefits Japan rather than the EEFSU region. First, despite a relatively high marginal abatement cost, the rate of return of capital in Japan falls less than in the US and the EU, making profitable to invest in Japan (in terms of the Figure 3, this implies that the actual rate of return falls less than the target rate and that investors in Japan moves gradually down and rightward along their expected investment schedule). Second, the size of the capital market in Japan is much larger than in the EEFSU region and therefore better able to absorb large amounts of additional investments (a similar argument is provided in McKibbin et al., 1999).

7. Sensitivity analysis

The above analysis suggests that international capital mobility has little impact on the rate of leakage over the medium term for a set of parameters that can be considered as central. However, the uncertainty surrounding the value of these parameters is large and past studies have demonstrated that the rate of leakage is sensitive to certain assumptions. Thus there is a need to assess how robust is the above outcome about capital mobility to changes in the value of some key parameters. This section is based on a reduced version of GDYN-E with only 3 regions (Annex1 countries, Energy exporting countries (Eex) and the Rest of the World region ROW). Sensitivity of the leakage generated through investment reallocation is assessed with respect to i) the value of the supply elasticity of coal; ii) the value of the Armington trade elasticities of substitution; iii) the value of the elasticities describing the substitution possibilities, including the interfuel substitution elasticities and iv) the investment elasticity.

7.1. The supply elasticity of coal.

As expected, the leakage rate increases when the value of the supply elasticity of coal is reduced. But only small values of the coal supply elasticity (below unity) yield substantial leakage rates[17]. In addition, the leakage function shifts upward over time due to the dynamic effects of investment reallocation. While the impact of investment reallocation is virtually the same for most values of the coal supply elasticity, it becomes much more pronounced for small elasticity values, as the profitability of investment in non-Annex 1 countries is enhanced by lower energy prices. Together, very low values of the supply elasticity of coal and the associated investment reallocation can lead to leakage rates as high as 30 per cent.

7.2. The trade substitution elasticities.

The Figure 9 shows the relationship between leakages and the value of the trade substitution elasticities, with the vertical axe corresponding to the elasticity values used in the central case[18]. Higher values of the Armington elasticities increase the amount of leakage but even values ten times higher than in the central case do not yield leakage rates higher than 10 per cent in 2000. However, the slope of the 2010 leakage curve is

[17] A finding that is consistent with the sensitivity analysis made in a static framework by Burniaux and Oliveira Martins (2000).

[18] In the central case, the values of the elasticity of substitution between domestic and imported non-energy goods range around 2.3 and the values of the elasticity of substitution between imported non-energy goods from different countries/regions of origin are around 5.

steeper than in 2000, suggesting that the dynamic component of the leakage trough capital mobility is higher, the higher the value of the trade elasticity.

7.3. The inter-factor substitution elasticities.

The Figure 10 draws the leakage rate as a function of the values of the inter-factor substitution elasticities with the vertical axe corresponding to the values of these elasticities in the central case[19]. This function has a typical U shape that reflects opposite influences of demand and substitution effects[20]. With relatively low susbstitution elasticities, the demand effect dominates in Annex 1 countries (all fuel demands decrease) and, given the assumed dissymmetry in supply reactions of coal and crude oil, “negative leakages” are higher, the higher the degree of inter-fuel substitution (hence, the declining section of the U-shape function on Figure 10). For high values of the inter-fuel substitution elasticity, the substitution effect dominates in Annex 1 countries : the demand for low-carbon energy increases substantially and , as this energy is in limited supply, its international price increases inducing a shift towards coal demand in the non-Annex 1 countries (hence, the upward sloped section of the leakage function in Figure 10). Though it directly depends on the degree of inter-fuel substitution, the U shape of the leakage function really reflects the assumptions underlying the supply of the various energy sources.

For levels of inter-factor substitution equal or higher than in the central case, the impact of international factor mobility remains negligible. On contrary, a lower degree of inter-factor substitution generates fairly substantial amounts of leakages through the channel of worldwide investment reallocation. The explanation is that a higher degree of complementarity between energy and capital increase the loss of profitability of investment in countries that undertake emission reductions, providing more incentive to investors for revising their investment decisions. The Figure 10 illustrates that the amount of leakage that can be generated under these circumstances is very important, leading to leakage rates up to 60 per cent in 2010 for very low values of the inter-factor substitution elasticities.

7.4. The investment elasticity

A key parameter in the investment response in GDYN-E is the slope of the expected investment schedule (see Figure 2), as determined by the value of the investment elasticity. The Figure 11 shows the leakage rate as a function of the value of the investment elasticity, with the vertical axe corresponding to the value used in the central

[19] In the central case, the value of the substitution elasticity between capital and the energy bundle is equal to 0.5; the value of the substitution elasticity between electricity and the non-electricity bundle equals 1; the value of the substitution elasticity between coal and the non-coal bundle equals 0.5 and the value of the substitution elasticity between the remaining fossil fuels equals 1. For sensitivity purpose, all these elasticity values are multiplied by the same scaling factor (corresponding to the horizontal axe on Figure 10.

[20] A similar U-shaped relationship is described in Burniaux and Oliveira Martins, 2000.

case[21]. Lower elasticity values mean that investors respond to smaller changes of the expected rate of return by larger changes of investment. This situation would imply a larger degree of international capital mobility. On contrary, larger values of the investment elasticity imply that relatively larger changes of the expected rate of return will result into smaller changes of investment, hence a lower degree of international capital mobility. As expected, the leakage increases the lower is the value of the investment elasticity (thus the higher the investor reaction to changes of expectations). However; the total variation of the leakage rate over a wide range of values of the investment elasticity does not exceed 6 per cent (Figure 11).

There is a large uncertainty about the investors response[22] but, according with this result, this uncertainty should not affect the conclusions about the leakage rate significantly.

8. Conclusions

This paper analyses the influence of international investment reallocation in the context of unilateral reductions of GHGs emissions undertaken by industrialized countries. The analysis is based on the simulation results obtained by using a recursively dynamic AGE model recently developed at the Center for Global Trade Analysis (GDYN-E) to simulate the economic consequences of the Kyoto Protocol. These results show that, for most parameter values, the amount of leakage associated to the implementation of the Protocol remain modest. This outcome remains valid even taking account of the dynamic effects arising from the worldwide reallocation of investment. Over the time horizon of the Protocol, the results from GDYN-E do not markedly differ from results of similar model that does not incorporate capital mobility.

There are however a number of conditions under which investment reallocation may generate substantial amount of carbon leakage. These conditions involve :

- Longer term dynamic effects in the absence of back-stop technologies;
- A very inelastic world supply of coal;
- Very high trade substitution elasticities;
- A relatively high degree of complementarity between capital and energy as well as a low level of inter-fuel substitution.

The latter condition implies that transient rigidities in technology adjustment, possibly implying some medium-term complementarity between capital and energy may generate higher leakage levels than simulated in the current version of GDYN-E[23]. Other conditions, however, are unlikely to prevail in reality.

[21] This elasticity is equal to 10 in the central case. This means that investors expect a 1 per cent increase of the investment to result into a 10 per cent fall of the rate of return.
[22] And the value that is used in the central case is no more than arbitrary.
[23] This could be introduced in GDYN-E by assuming a vintage structure of capital with different degree of technology substitution associated with new and old capital vintages.

These results also confirm the importance of the supply behaviors of coal and oil producers rather than the aggregate investment response in determining the magnitude of the carbon leakage. In most existing GE models, the decision of these producers is rudimentary represented by using aggregate supply elasticities. Unfortunately, there is so far relatively little evidence in the econometric literature concerning the value of these elasticities [24]. Furthermore, it should be noted that existing estimates are based on time-series regressions whereas, in principle, cross-sectional or pooled data regressions would be preferable for the calibration of GE models. They provide a better approximation of long-run relationships, which fit better with the structure underlying GE models. Without more empirical work on the supply response of coal and oil producers little more will be learned about the likely magnitude of the carbon leakage in the case of an unilateral action by a group of countries to reduce their GHG emissions.

[24] See Burniaux and Oliveira Martins, 2000 for a review of econometric estimates of the value of the supply elasticity of coal.

References

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

Babiker M., H.D.Jacoby (1999), "Developing country effects of Kyoto-type emissions restrictions.", mimeo, Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology .

Bernard A.L., Vielle M. (2000), "Preliminary results of sensitivity analysis on leakage with GEMINI-E3/GemWTraP", draft, May .

Bollen J., , T.Manders, H. Timmer (1999), "Kyoto and carbon leakage: simulations with WorldScan", mimeo, paper presented at the IPCC Working Group III Expert Meeting, May-27-28, The Hague .

Botteon M., Carraro C. (1998), "Environmental coalitions with heterogeneous countries: burden-sharing and carbon leakages", Nota di Lavoro 24.98, March .
Burniaux JM, J. Oliveira-Martins (2000), "Carbon Emission Leakages : a General Equilibrium View.", Economic Department Working Paper No 242, OECD .

Carraro C. (1998), "Beyond Kyoto : A game theoretic perspective", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September .
Ianchovichina E., R. McDougall (2001), "Thoretical Structure of Dynamic GTAP", GTAP Technical Paper No. 17, Edition 1.1, January .

Lee H., Oliveira-Martins J. , van der Mensbrugghe D. (1994), "The OECD GREEN Model: an updated overview", OECD Development Centre Technical Paper No 97, August , OECD, Paris .

Light M., C. Koldstad, T. Rutherford (1999), "Coal markets and the Kyoto Protocol", mimeo, November .

Manne A., R.G. Richels (1998), "The Kyoto Protocol : a cost-effective strategy for meeting environmental objectives ?", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September 1998, forthcoming in The Energy Journal, May 1999.

McKibbin W., M.T. Ross, R.Shackleton and P.J. Wilcoxen (1999), "Emissions trading, capital flows and the Kyoto Protocol", paper presented at the IPCC Working Group III Expert Meeting, May 27-28, The Hague .

OECD (1995), Global Warming : Economic Dimensions and Policy Responses, OECD, Paris .

OECD (1999), "Action Against Climate Change: The Kyoto Protocol and Beyond.", Paris .

Oliveira Martins J. (1995), "Unitlateral emission control, energy-intensive industries and carbon leakages", in OECD(1995) , OECD, Paris .

Truong T.P. (1999), "GTAP-E: Incorporating Energy Substitution into the GTAP Model", GTAP Technical Paper No. 16, December .