International Emissions Trading Scheme and EUropean Emissions Trading Scheme : what linkages ?

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Résumé

Simultaneity between commitment periods (2008-2012) of International Emissions Trading (IET) scheme and EUropean Emissions Trading Scheme (EU-ETS) is likely to generate distortions in terms of burden's distribution among sectors. There will be two levels of trading : a country and an entity level, which both need to be consistent with each other. Besides, features of these two "cap and trade" emissions trading schemes are not the same. Thus, to reach international targets, each European government will have to adopt an additional environmental policy concerning sectors only covered by the IET. This policy may consist in implementing a tax rate on emissions of these latter sectors. The level of such a tax will depend on the effort realized within the European market. Indeed, if the domestic objective is low (within EU-ETS), then sectors only included in the Kyoto program will have to support the main part of the environmental constraint. We propose in this article a modeling of this two-level environmental policy, focusing on the additional tax rate, introducing several cases of linkages. It allows us to obtain empirical estimations of the efforts that will be demanded to non-covered polluting sectors in European countries, and to show how these efforts will be distributed. It also allows us to calculate the different carbon prices.

Keywords : Kyoto Protocol, EU-ETS, co-existence of domestic and international emissions trading systems, carbon price, environmental policy.
JEL Classification : Q53 ; Q58 ; Q28

1 Introduction

Simultaneity between commitment periods (2008-2012) of International Emissions Trading scheme (hereafter IET) and EUropean Emissions Trading Scheme (hereafter EU-ETS)

is likely to generate distortions in terms of burden's distribution among sectors. Indeed, the features of these two "cap and trade" emissions trading schemes are not the same. The first one is established on a country level whereas the second one is defined on an entity level. Besides, IET covers sectors not initially included in EU-ETS. To reach international targets, each European government will have to adopt an additional environmental policy concerning these latter sectors. This policy may consist in implementing a tax rate on emissions of sectors only included in the Kyoto Protocol. The level of such a tax will depend on the effort realized within the European domestic market by the sectors covered by the EU-ETS. Anyhow, several carbon prices will coexist : an international price within the IET scheme, a European price for covered sectors within the EU-ETS, and domestic prices –the tax rates– for non-covered European sectors. This will induce distortions in the behavior of firms and states, and will certainly not contribute to the equity and the transparency of the whole carbon device.

We propose in this paper a modelling of this two-level environmental policy instrument, focusing on the additional tax rate that could enable a European government to fulfill its international obligation in presence of a domestic market. It allows us to obtain empirical estimations of the efforts that will be demanded to polluting sectors in European countries, and to show how these efforts will be distributed, under different assumptions about the behavior of Europe on the international market. It also allows us to estimate the different carbon prices.

Since February 2005, the Kyoto Protocol on Climate Change has entered into force. It implements an International Emissions Trading Scheme as a mechanism of flexibility to limit greenhouse gases emissions. The first commitment period will start in 2008 and last for five years. The main objective, for Parties member of Annex B[1], is to reduce the average level of emissions by 5.2 percent compared to 1990's level. Each Party receives a pre-determined amount of allowances (*Assigned Amount Units* or AAU, expressed in metric tonnes of CO_2 equivalent) to fulfill its obligation notified in the Annex A of the Treaty. These units or permits give a right to emit pollutants up to a certain level. Each government is allowed to sell or purchase units on the international market to be in compliance. In this framework, Europe, considered as a "Party", is required to reduce its emissions level by 8 percent by comparison to the initial level of 1990. In addition, the overall European objective of emissions reduction has been distributed among European countries in the "*European Burden Sharing Act*".

In spite of the fact that the international market is defined on a country level, the Treaty does not exclude the opportunity to implement domestic trading systems in order to reach targets at least cost : according to Article 17, *"The conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3. Any such trading shall be supplemented to domestic actions for the purpose*

[1]Annex B of the Treaty brings together OECD countries participating to the Protocol, plus eastern European countries and ex-soviet block countries, less the United-States *(and Australia ?)*.

of meeting quantified emission limitation and reduction commitments under that article." Thus, according to the Protocol, the European Commission decided in 2003 to implement a domestic environmental policy establishing a European Union Emissions Trading Scheme[2] (European Commission, 2003). The objective of the EU-ETS was to lower costs of compliance at the international level by gradually reducing emissions, and to enable entities to adapt themselves to a new instrument of environmental policy. This European market is thus established on an entity level. The first commitment period of the European emissions trading system began before the first commitment period of Kyoto, in 2005, and the second one will span over the years 2008-2012. Plants included in EU-ETS receive some units called *EUropean Carbon Currency,* and can trade these European units within the market. The European targets within EU-ETS are determined by each European government and reported in the National Allocation Plans. Each NAPs is submitted to the approbation of the European Commission, in order to respect the international obligations.

Hence, both systems will be operating during the same period, 2008-2012. So, there will be two levels of trading during this period : a country level and an entity level, which need to be consistent with each other (Butzengeiger *et al.*, 2001). Each European state will have to respect on the one side the European cap associated with the EU-ETS, and on the other side the international target within IET.

However, these two systems are different : while the international system covers the six main greenhouse gases[3], EU-ETS covers only CO_2 emissions. Moreover, the international market covers sectors not included in the European system such as transports, agriculture, waste and housing-tertiary, in addition of those included in EU-ETS such as energy activities, mineral industries, oil refineries.

In this paper, we focus on the behavior of a European government facing this double environmental constraint. As mentioned above, within the EU-ETS, governments are required to determine the level of emissions reduction, taking into account their international objective. The abatement realized through the European emissions trading system will be taken into account for the international compliance at the end of the first commitment period, as IET covers emissions of sectors included in EU-ETS. This situation implies a distribution of the burden among sectors covered by EU-ETS and sectors only included in IET. As notified by Olivier Godard (2005), if the domestic objective is low, then sectors only included in the Kyoto program will have to support the main part of the environmental constraint. Indeed, the presence of a domestic market generates distortions in terms of burden's distribution among sectors.

We consider that European governments will implement a tax rate on emissions of non-covered sectors, to ensure the international compliance. These tax rates will be the instruments that guarantee the linkage between the two systems. They will depend on the burden distribution among sectors, i.e. on the abatement realized within the domestic

[2]European Directive 2003/87/CE, called "*Directive PEN*" published in the Official Journal of the European Union on October the 13th, 2003.

[3]The six main greenhouse gases concerned by the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC_s), perfluorocarbons (PFC_s) and sulphur hexafloride (SF_6).

market compared to the international constraint.

To address this policy question, we consider separately the European emissions trading system and the international one.

We study in the following section (2) the behavior of European entities trading on the European market. We deduce the optimal level of abatement of each country, holding account of the constraints established in the different NAPs. Then, we deal with the consequences of a tax implementation on the behavior of non-covered European entities, and we describe the relation between the level of the tax rate of each European country and the level of the domestic constraints. We finally study, as a benchmark, the efficient solution, that is to say the initial allocations for covered sectors and the tax rates for non-covered sectors that a European central planner would implement in order to satisfy the Kyoto target. In section 3, we introduce the International Emissions Trading scheme and describe the behavior of countries participating to it, distinguishing Europe and the "Rest of the Parties". We consider three possible cases. In the first one, a European regulator is the representative actor on the international market ; he is able to purchase or sell international permits to ensure the compliance and to impose to European countries the same tax rate on their non-covered sectors, equal to the international carbon price. The second case, there is no European regulator and national governments neglect the possibilities of cost reduction offered by the international market and fix their own tax rate, to attain their Kyoto objective within the *European Burden Sharing Act*. Finally, in the third case, a European regulator acts on the international market only and delegates to the countries the task of fixing their tax rate in order to attain the required abatement rate. Then, section 4 provides numerical estimations of the previous results. Finally, we conclude the article (section 5) by emphasizing the consequences of the actual environmental policies and proposing extensions to the model.

2 Europe

We consider that the EUropean Emissions Trading Scheme works independently from IET, over the period 2008-2012. European countries are indexed by k, with $k = 1, ..., n$. We assume that in a given European country k, firms belonging to covered sectors can trade permits not only with others firms belonging to covered sectors of the same country k, but also with firms of another European country. This assumption is a simplification of reality[4]. Moreover, we assume that European sectors are not allowed to engage, for their compliance, units associated with IET, such as project-based mechanisms units (ERUs and/or CERs)[5]. This assumption seems to be reasonable, because, at the moment, the

[4]In reality indeed, modelling of intra-Europe trades requires to define rules about reporting and units conversion. To be consistent with the Kyoto Protocol, trade between European firms in different member-states implies adjustments of countries AAUs amounts (see Carlen, 2004).

[5]Industrial trading sectors are allowed to use CERs or/and ERUs for their compliance through the "*Linking Directive*", but importation of broad units are limited. ERUs are credits associated to mechanisms of Joint-Implementation and CERs are credits associated to Clean Development Mechanisms.

amount of CERs and ERUs used by European entities is still marginal.

2.1 Covered sectors : the EUropean Emissions Trading Scheme

The sectors participating to EU-ETS are indexed by $j = 1, ..., N$. These aggregate sectors are energy (electricity), ferrous metals, mineral industries and chemistry, pulp and paper industries and other industries. They are the same in all European countries (*cf.* Annex I of Directive PEN).

According to the different NAPs, each sector j in a given European country k receives an amount of permits $\overline{e}_{kj}$, where $\sum_{j=1}^{N} \overline{e}_{kj} = \overline{e}_k$. A low $\overline{e}_{kj}$ means that the constraint is stringent, because it represents the level of authorized emissions. The sum over the European countries of each national environmental allocations $\overline{e}_k$ represents the overall European objective : $\sum_{k=1}^{n} \overline{e}_k = \overline{e}_{\text{ets}}$.

It is worth emphasizing that the usual logic of emissions trading systems is reversed here : the European countries decide on their own initial allocation $\overline{e}_k$, and the addition of these decisions determines the overall constraint $\overline{e}_{\text{ets}}$. The incentive for each European country not to choose an initial allocation equal to its business as usual emissions comes from the threat of the European Commission not to approve its NAP (see the case of the French NAP in December 2006).

We note e^0_{kj} the BAU (Business-as-usual) emissions of sector j in country k, i.e. emissions trends without any environmental policy. The total BAU emissions within EU-ETS for covered sectors are $\sum_{k=1}^{n} \sum_{j=1}^{N} e^0_{kj} = e^0_{\text{ets}}$. Moreover, a_{kj} is the abatement of sector j in country k. The remaining emissions after abatement are $e^0_{kj} - a_{kj}$.

The effort of abatement a_{kj} provided by a sector j induces a cost noted $C_{kj}(a_{kj})$. The abatement cost function is supposed twice differentiable and strictly convex : $C'_{kj}(a_{kj}) > 0$ and $C''_{kj}(a_{kj}) > 0$[6]. Abatement cost functions can differ among sectors and across countries because levels of technology are different (Jacoby, 1999).

Each sector j has to buy (or can sell) European permits at a competitive price p_e to fill the gap between remaining emissions (after abatement) and its quantified target[7].

Then, each covered sector j seeks to minimize its compliance costs, by determining the optimal level of abatement :

$$\min_{a_{kj}} C_{kj}(a_{kj}) + p_e[(e^0_{kj} - a_{kj}) - \overline{e}_{kj}] \quad \forall j = 1, ..., N.$$

The first order condition yields

$$C'_{kj}(a_{kj}) = p_e \quad \forall j = 1, ..., N \text{ and } \forall k = 1, ..., n. \tag{1}$$

So, as it is well known, the marginal abatement costs are equalized in each sector of each country participating to the European market, and the common marginal abatement cost is equal to the price of permits.

[6]Further explanations about the chosen functional form of the abatement cost function will be given in the simulation.

[7]If the objective is not realized, the sector j will have to pay penalties for every unit of emission beyond the fixed cap. Here, we do not take into account this possibility.

The equilibrium on the European permits market is :

$$\sum_{k=1}^{n}\sum_{j=1}^{N}(e_{kj}^{0} - a_{kj}) = \overline{e}_{\text{ets}}.$$

The sum of effective emissions after abatement is equal to the emission cap. This equilibrium allows us to obtain the price of permits, that represents the level of the overall environmental constraint.

The equilibrium on the European permits market can also be written as follows :

$$\sum_{k=1}^{n}\sum_{j=1}^{N} a_{kj} = e_{\text{ets}}^{0} - \overline{e}_{\text{ets}}. \tag{2}$$

The right-hand side member of equation (2) can be interpreted as the effort in terms of emissions reduction imposed on covered European sectors, and the left-hand side member is indeed the total abatement realized within EU-ETS.

2.2 Non-covered sectors : taxation

We consider here polluting sectors which are not included in EU-ETS's program. Their greenhouse gases emissions are however involved for the international compliance within the Kyoto Protocol. So, we assume that each European government implements an additional environmental policy, here a tax on emissions, in order to satisfy the international objectives. The co-existence of a domestic and an international emissions trading scheme, i.e. two environmental policy instruments, implies a distribution of the burden among sectors. Intuitively, we can suppose that if the effort realized within the domestic market is low, then the tax rate imposed on non-covered European sectors will be high, in order to respect the commitments.

Non-covered sectors included in IET are specifically transport,and others, such as agriculture, waste and housing-tertiary. Thus, we consider two representative non-covered sectors in each European country k, by simplification. These sectors are indexed by $h = 1, 2$. The tax rate on these sectors'emissions is noted τ_k. We assume a single tax rate on all non-covered sectors, in line with the usual implemented fiscal policies. It is exogenous for non-covered sectors, but will be determined by each government, as a function of the effort realized within the domestic market later, when the international market will be introduced. Then, each European government will be able to define the level of tax that enables it to comply its international obligations.

For the non-covered sectors in a given European country k, the abatement is noted b_{kh} and the baseline emissions f_{kh}^{0}. The emissions after abatement are then $(f_{kh}^{0} - b_{kh})$. We note $D_{kh}(b_{kh})$ the abatement cost function, which is twice differentiable and convex : $D'_{kh}(b_{kh}) > 0$ and $D''_{kh}(b_{kh}) > 0$. Both non-covered sectors seek to minimize its costs by choosing its level of abatement :

$$\min_{b_{kh}} D_{kh}(b_{kh}) + \tau_k(f_{kh}^{0} - b_{kh}) \quad \forall h = 1, 2.$$

Writing the first order condition gives :

$$D'_{kh}(b_{kh}) = \tau_k \quad \forall h = 1, 2 \text{ and } \forall k = 1, ..., n. \tag{3}$$

The abatement b_{kh} of the non-covered sector depends on the tax rate : the higher the tax rate, the higher the effort of abatement.

2.3 Distribution of the effort among sectors within European countries

Let us consider the behavior of a European government facing these two instruments to attain a given international constraint.

Total effective emissions in country k are $\sum_{j=1}^{N}(e^0_{kj} - a_{kj}) + \sum_{h=1}^{2}(f^0_{kh} - b_{kh})$, where a_{kj} is function of the European permit price p_e and b_{kh} is a function of τ_k, given by the previous first order conditions (1) and (3). These total emissions are bounded by the Kyoto Protocol and more precisely by the *European Burden Sharing Act*. To reach a given international target noted θ_k at the moment, the regulator of each European country will have to determine a couple $(\overline{e}_k; \tau_k)$. The regulator has determined *ex-ante* $\overline{e}_k$ within the European market and must then implement the tax rate τ_k that enables him to be in compliance.

For the European country k, the iso-abatement curve associated with an abatement objective θ_k gives the relationship between the tax rate supported by the non-covered sectors and the level of the constraint imposed on covered sectors. It can be written as follows :

$$\sum_{j=1}^{N} a_{kj} + \sum_{h=1}^{2} b_k = \theta_k,$$

or, the abatement levels a_{kj} and b_{kh} being given by the first order conditions (1) and (3) and the price of European permits by equation (2) :

$$\begin{aligned} \sum_{j=1}^{N} C'^{-1}_{kj}(p_e) + \sum_{h=1}^{2} D'^{-1}_{k}(\tau_k) &= \theta_k, \\ \text{with } \sum_{k=1}^{n}\sum_{j=1}^{N} C'^{-1}_{kj}(p_e) &= e^0_{\text{ets}} - \overline{e}_{\text{ets}}. \end{aligned} \tag{4}$$

We can see that the weight of the initial allocation $\overline{e}_k$ of a given European country k in its iso-abatement curve is "diluted" in the global constraint $\overline{e}_{\text{ets}}$ through the European market. Every country is then incited to propose to the European Commission NAPs assigning an effort to its covered sectors as small as possible, hoping that the others will do the job without enforcing it to increase the tax rate τ_k to meet a given abatement objective.

2.4 Benchmark : the efficient solution

We assume the existence of a European central planner who seeks to minimize the total abatement cost of the European Union.

The abatement of a covered sector j in a European country k is by definition equal to the difference between its BAU emissions and the sum of its initial allocation of permits and its purchase (sell) of European permits, denoted ε_{kj}, with $\varepsilon_{kj} \gtreqless 0$:

$$a_{kj} = e^0_{kj} - (\overline{e}_{kj} + \varepsilon_{kj}).$$

The total abatement of the covered sectors of country k is then :

$$\sum_j a_{kj} = \sum_j e^0_{kj} - \sum_j \overline{e}_{kj} - \sum_j \varepsilon_{kj} = e^0_k - \overline{e}_k - \sum_j \varepsilon_{kj}. \tag{5}$$

The abatement of the non-covered sectors in a country k allows it to comply with its Kyoto commitment. For this, it is necessary that the total abatement of country k equals the difference between its BAU emissions and its Kyoto commitment $\overline{e}_{Ek}$ augmented by its purchases of European permits and of Kyoto permits, denoted ε^K_k :

$$\sum_j a_{kj} + \sum_{h=1}^{2} b_{kh} = e^0_k + \sum_{h=1}^{2} f^0_{kh} - \left(\overline{e}_{Ek} + \sum_j \varepsilon_{kj} + \varepsilon^K_k \right). \tag{6}$$

Equations (5) and (6) allows us to obtain the abatement of the non-covered sector of country k :

$$\sum_{h=1}^{2} b_{kh} = \sum_{h=1}^{2} f^0_{kh} + \overline{e}_k - \left(\overline{e}_{Ek} + \varepsilon^K_k \right) \tag{7}$$

The constraints that must be verified are the following :

$$\sum_k \sum_j \varepsilon_{kj} = 0, \tag{8}$$

$$\sum_k \varepsilon^K_k + \varepsilon^K_i = 0, \tag{9}$$

meaning that the sum of net purchases of permits must be equal to zero on the European market and on the Kyoto market, where ε^K_i is the purchase of permits of the non-European countries on the Kyoto market. This variable is taken as exogenous by the European central planner.

Efficiency requires the minimization of the total abatement cost with respect to the net purchases of permits on the two markets and the initial allocations given to covered sectors :

$$
\begin{aligned}
\min_{\varepsilon_{kj},\overline{e}_{kj},\varepsilon_k^K} K_E(a_E) &= \sum_k \left(\sum_j C_{kj}(a_{kj}) + \sum_{h=1}^{2} D_{kh}(b_{kh}) \right) \\
\sum_k \sum_j \varepsilon_{kj} &= 0 \\
\sum_k \varepsilon_k^K + \varepsilon_i^K &= 0.
\end{aligned}
$$

The Lagrangian is then :

$$
\mathcal{L} = \sum_k \left(\sum_j C_{kj}(a_{kj}) + \sum_{h=1}^{2} D_{kh}(b_{kh}) \right) + p_1 \sum_k \sum_j \varepsilon_{kj} + p_2 \left(\sum_k \varepsilon_k^K + \varepsilon_i^K \right),
$$

where p_1 and p_2 are the implicit carbon prices on the two markets.
The first order conditions are :

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \varepsilon_{kj}} &= C'_{kj}(a_{kj}) \frac{\partial a_{kj}}{\partial \varepsilon_{kj}} + p_1 = 0, \\
\frac{\partial \mathcal{L}}{\partial \overline{e}_{kj}} &= C'_{kj}(a_{kj}) \frac{\partial a_{kj}}{\partial \overline{e}_{kj}} + D'_{kh}(b_{kh}) \frac{\partial b_{kh}}{\partial \overline{e}_{kj}} = 0, \\
\frac{\partial \mathcal{L}}{\partial \varepsilon_k^K} &= C'_{kj}(a_{kj}) \frac{\partial a_{kj}}{\partial \varepsilon_k^K} + D'_{kh}(b_{kh}) \frac{\partial b_{kh}}{\partial \varepsilon_k^K} + p_2 = 0,
\end{aligned}
$$

i.e.

$$
C'_{kj}(a_{kj}) = p_1 = D'_{kh}(b_{kh}) = p_2 \qquad \forall k, j \textit{ and } h. \tag{10}
$$

The efficient solution then consists in a unique price of carbon ($p_1 = p_2$), and in the equality of the marginal costs of abatement for all sectors across all European countries. It is then possible to obtain the efficient initial allocations that should be granted to each sector in each European country in order to satisfy these conditions, for any given net demand of Kyoto permits by non-European countries.

This solution will be used as a benchmark in the numerical exercises performed below, and we will in particular evaluate the departure of the actual initial allocations from the efficient ones.

The next section describes the International Emissions Trading scheme established on a country level. The overall objective to respect is a European objective (a reduction of 8% compared to the level of emissions in 1990) which is then distributed among European countries. It means that the tax rate depends also on the overall European compliance. The behavior of each European government on this market will provide the additional tax rate to be implemented.

3 The International Emissions Trading scheme

The International Emissions Trading scheme will run from 2008 to 2012 and is established on a country level : governments are responsible for their compliance. Annex B Parties will have to reduce by 5.2 % their average level of emissions (compared to the base year, 1990) over the period. Parties participating to the international permits market are able to trade AAUs to be in compliance.

We consider that each Party is price taker and that the international market is competitive. We note the price of international permit p.

In addition, we assume the International Emission Trading scheme is represented by two agents considered as two zones : "Europe", indexed by E and considered as a part of IET, and the "Rest of the Parties", indexed by i[8]

These two zones must respect an international "cap" noted $\overline{e}$. The initial allocations of permits to the two zones are $\overline{e}_E$ and $\overline{e}_i$, with $\overline{e}_E + \overline{e}_i = \overline{e}$. Hence, $\overline{e}$ corresponds to the global international objective of 5.2 % in average over the period 2008-2012.

3.1 The Rest of the Parties

The baseline emissions for the Rest of the Parties are noted e_i^0. Zone i has to fulfill its commitment $\overline{e}_i$ by reducing its polluting emissions or trading on the market. Notice that for zone i, all pollutant sectors stated in the Kyoto Protocol are included. There is no distinction among sectors. The abatement of zone i is noted a_i. The remaining emissions after abatement are $e_i^0 - a_i$.

As for other Parties, the activity of cleaning up is associated with a twice differentiable, increasing and convex abatement cost function $K_i(a_i)$, where $K_i' > 0$ and $K_i'' > 0$. To be in compliance at least cost, the country i is allowed to trade permits on the international market at the competitive permit's price p. Noticed that we do not introduce imperfect competition in the model.

Zone i minimizes its compliance costs :

$$\min_{a_i} K_i(a_i) + p\left[(e_i^0 - a_i) - \overline{e}_i\right],$$

yielding as usual :

$$K_i'(a_i) = p. \tag{11}$$

3.2 Europe

Europe, as a whole, must respect its overall objective $\overline{e}_E$, where each European country having its own objective of emissions reduction $\overline{e}_{Ek}$ notified in the *European Burden Sharing Act.* The actual institutional arrangements, and in particular the fact that Europe is considered as a whole zone, seem to suggest that the European actor on the market of

[8]Bulgaria, Canada, Japan, Liechenstein, Norway, New-Zealand, Romania, Russian Federation and Switzerland compose the "Rest of the Parties".

international permits will be a single European entity, that we name the European regulator. Nevertheless, we study here different scenarios concerning the behavior of European countries on the international market.

3.2.1 European regulator able to impose the national tax rates

Suppose first that there exists a European regulator able to impose to European governments the tax rates that they must apply to their non-covered sectors. Then, obviously, he must impose in each European country a tax rate on emissions of non-covered sectors equal to the price of international permits, given that this price reflects the global environmental constraint :

$$\tau_k = p \quad \forall k. \tag{12}$$

The abatement rate of the non-covered sectors of country k is then $b_k = D'^{-1}_k(p)$. Everything goes as if the non-covered sectors of all European countries were allowed to trade permits directly on the international market, and the equilibrium of the market is, in terms of abatements :

$$a_i + \sum_{k=1}^{n} \sum_{h=1}^{2} b_{kh} = e^0 - \overline{e}. \tag{13}$$

If we suppose that targets supported by covered sectors within EU-ETS are low, then the effort to realize in order to reach obligations at the international level is high (i.e. the gap to fill is important). It implies that the price p_e associated to the European market is low and as the effort supported by non-covered sectors is high then the price of the international market will be high, i.e the demand on IET is higher (the level of the tax rate is thus high too). The environmental effort is consequently more important for sectors such as agriculture, transports, housing-tertiary.

This solution is not very plausible. Fixing the tax rates is still a state prerogative, that will not be so easily abandoned to the European regulator.

3.2.2 National regulators fixing their own tax rates

So let us consider now that each national regulator does not take into account opportunities provided by the international market. It implies that each European government determines its own tax rate τ_k, in order to reach its Kyoto target $\overline{e}_{Ek}$, the effort realized by the covered sectors being considered as given.

The iso-abatement curve (4) is now :

$$\sum_{j=1}^{N} C'^{-1}_{kj}(p_e) + \sum_{h=1}^{2} D'^{-1}_{kh}(\tau_k) = \sum_{j=1}^{N} e^0_{kj} + \sum_{h=1}^{2} f^0_{kh} - \overline{e}_{Ek},$$

where p_e is given by equation (2), from which we deduce

$$\tau_k = \sum_{h=1}^{2} D'_{kh} \left(\sum_{j=1}^{N} (e^0_{kj} - C'^{-1}_{kj}(p_e)) + \sum_{h=1}^{2} f^0_{kh} - \overline{e}_{Ek} \right). \tag{14}$$

The national regulator will implement this tax rate on non-covered sector emissions. It depends on the level of remaining emissions of covered sectors and is an increasing function of the BAU emissions of the non-covered sector.

The obvious drawbacks of this solution is that Europe does not take advantage of the international market to reduce its abatement costs. Its merit is that each European country remains sovereign as far as its fiscal policy is concerned.

3.2.3 European regulator acting on the international market only

We suppose now that there exists a European regulator whose job is to determine jointly the total European rate of abatement and the net purchases of international permits, given the Kyoto constraint on European emissions $\overline{e}_E$.

The total European BAU emissions are noted e_E^0. They are the sum of the emissions of covered and non-covered sectors :

$$e_E^0 = \sum_{k=1}^{n}\sum_{j=1}^{N} e_{kj}^0 + \sum_{k=1}^{n}\sum_{h=1}^{2} f_{kh}^0 = e_{\text{ets}}^0 + \sum_{k=1}^{n}\sum_{h=1}^{2} f_{kh}^0. \tag{15}$$

To determine the total level of abatement, the European regulator minimizes its compliance costs. We suppose for the moment that he uses an aggregate abatement cost function for Europe $K(a_E)$, and we will precise later what this aggregate function can be. Thus the program of cost minimization for the European regulator acting on the international market is written as follows :

$$\min_{a_E} K_E\left(a_E\right) + p[\left(e_E^0 - a_E\right) - \overline{e}_E],$$

and the first order condition yields :

$$K_E'\left(a_E\right) = p. \tag{16}$$

The competitive price of an international permit is given by the equilibrium on the market :

$$(e_i^0 - a_i) + (e_E^0 - a_E) = \overline{e},$$

or, in terms of abatements,

$$a_i + a_E = e^0 - \overline{e}, \tag{17}$$

where a_i and a_E are given by the first order conditions (11) and (16).

We then assume again that European constraints for covered sectors are given, while the tax rates imposed on non-covered sectors are still undetermined. The tax rate must compensate the difference between European emissions of covered sectors and the international European objective.

The total European abatement effort within the IET is also the sum of the abatement efforts of the n European countries :

$$a_E(p) = \sum_{k=1}^{n} \left(\sum_{j=1}^{N} a_{kj}(p_e) + \sum_{h=1}^{2} b_{kh}(\tau_k) \right), \tag{18}$$

where $a_E(p)$ is given by equation (16), $a_{kj}(p_e)$ by equation (1) and $b_k(\tau_k)$ by equation (3).

The relationship between the sectoral cost functions and the aggregate cost function used by the European regulator is given in the Appendix.

As we assume that allocations for covered sectors are given, then each tax rate must be calculated in a way to satisfy equation (18). Obviously, a unique tax rates system solution of this equation does not exist. A constraint must be added, describing the repartition of efforts among the European countries, which could be proportional to their emissions reduction objective of the *European Burden Sharing Act.* We would then have

$$\begin{aligned} & a_{Ek}(p_e, \tau_k) = \mu \overline{e}_{Ek} \\ \Rightarrow \quad & a_E(p) = \mu \sum_k \overline{e}_{Ek} \\ \Rightarrow \quad & \mu = \frac{a_E(p)}{\overline{e}_E} \\ \Rightarrow \quad & a_{Ek}(p_e, \tau_k) = a_E(p) \frac{\overline{e}_{Ek}}{\overline{e}_E}, \end{aligned} \tag{19}$$

which allows us to obtain τ_k knowing p_e and p.

4 Simulations

The purpose of this section is to simulate the previous model and to determine for every European country the real tax rate that should be implemented and consequently the resulting abatement for non-covered sectors.

4.1 The tax rates for quadratic abatement cost functions

We suppose that the sectoral abatement cost functions are quadratic :

$$\begin{aligned} C_{kj}(a_{kj}) &= \frac{\alpha_{kj}}{2} a_{kj}^2, \\ D_{kh}(b_{kh}) &= \frac{\beta_{kh}}{2} b_{kh}^2. \end{aligned}$$

The parameters $\alpha_{kj} > 0$ and $\beta_{kh} > 0$ represent the level of abatement technology, which differs between member-states and between sectors. We assume that $\beta_{kh} < \alpha_{kj}$ and

justify this inequality by the fact that production for covered sectors is more malleable (see Jacoby, 1999). Opportunities of substitution in the process of production (i.e substitution between polluting and clean input) are more important for covered sectors, in particular for energy. Moreover, the convexity and degree of steepness of the function are impacted by specific assumptions about BAU emissions. Actually, the more elastic the system, the lowest the cost of reduction. It is important to notice that the slope and the convexity of the abatement function determine mainly the optimal path of emissions under certainty as well as under uncertainty (Baker, 2003). Here, noticed that abatement can not be negative, otherwise the cost function would be negative. We consider a quadratic abatement cost function to underline the convexity of the costs and because if the cost function was linear,“ *...then it would be optimal to delay abatement until the last period...*". (Baker, 2003). Using quadratic cost function, implies that the marginal cost of abatement is a linear function of the carbon price.

We can deduce through the first order conditions (1) and (3) that

$$\begin{aligned} a_{kj} &= p_e \frac{1}{\alpha_{kj}}, \\ b_{kh} &= \tau_k \frac{1}{\beta_{kh}}, \end{aligned}$$

and the equilibrium of the market for emission permits (2) yields :

$$p_e = \frac{e^0_{\text{ets}} - \overline{e}_{\text{ets}}}{\sum_{k=1}^{n} \sum_{j=1}^{N} \frac{1}{\alpha_{kj}}}.$$

Equation (4) reads :

$$p_e \sum_{j=1}^{N} \frac{1}{\alpha_{kj}} + \tau_k \sum_{h=1}^{2} \frac{1}{\beta_{kh}} = \theta_k,$$

from which we can deduce the tax rate that enables country k to reach an abatement level of θ_k :

$$\tau_k = \sum_{h=1}^{2} \beta_{kh} \left[\theta_k - \left(e^0_{\text{ets}} - \overline{e}_{\text{ets}} \right) \frac{\sum_{j=1}^{N} \frac{1}{\alpha_{kj}}}{\sum_{k=1}^{n} \sum_{j=1}^{N} \frac{1}{\alpha_{kj}}} \right].$$

We can now calculate the tax rates on non-covered European sectors in the different cases studies above.

4.1.1 Benchmark

We must find the $\overline{e}_{kj}$ that lead to the equalization of all the marginal abatement costs, for covered and non covered sectors, in every European country, given the international demand for permits ε_i^K.

This demand is of course related to the level of abatement of non-European countries :

$$\begin{aligned}\varepsilon_i^K &= e_i^0 - a_i - \overline{e}_i \\ &= e_i^0 - \frac{p}{\gamma_i} - \overline{e}_i.\end{aligned}$$

Equation (6) reads :

$$p\left(\sum_j \frac{1}{\alpha_{kj}} + \sum_{h=1}^{2} \frac{1}{\beta_{kh}}\right) = e_k^0 + \sum_{h=1}^{2} f_{kh}^0 - \left(\overline{e}_{Ek} + \sum_j \varepsilon_{kj} + \varepsilon_k^K\right),$$

and the sum of these equations over all European countries combined to the equilibrium constraints and the preceding expression of ε_i^K gives :

$$\begin{aligned}p\sum_k\left(\sum_j \frac{1}{\alpha_{kj}} + \sum_{h=1}^{2} \frac{1}{\beta_{kh}}\right) &= \sum_k\left(e_k^0 + \sum_{h=1}^{2} f_{kh}^0 - \overline{e}_{Ek}\right) - \sum_k\sum_j \varepsilon_{kj} - \sum_k \varepsilon_k^K \\ &= \sum_k\left(e_k^0 + f_k^0 - \overline{e}_{Ek}\right) + \varepsilon_i^K \\ &= \sum_k\left(e_k^0 + \sum_{h=1}^{2} f_{kh}^0 - \overline{e}_{Ek}\right) + e_i^0 - \frac{p}{\gamma_i} - \overline{e}_i.\end{aligned}$$

The carbon price is then :

$$p = \frac{\sum_k\left(e_k^0 + \sum_{h=1}^{2} f_{kh}^0 - \overline{e}_{Ek}\right) + e_i^0 - \overline{e}_i}{\frac{1}{\gamma_i} + \sum_k\left(\sum_j \frac{1}{\alpha_{kj}} + \sum_{h=1}^{2} \frac{1}{\beta_{kh}}\right)} \tag{20}$$

This allows us to obtain the abatements $a_{kj} = p/\alpha_{kj}$, $b_{kh} = p/\beta_{kh}$, $a_i = p/\gamma_i$, as well as

$$\begin{aligned}\overline{e}_{kj} + \varepsilon_{kj} &= e_{kj}^0 - \frac{p}{\alpha_{kj}} \\ \overline{e}_{Ek} + \varepsilon_k^K &= \sum_{h=1}^{2} f_{kh}^0 + \overline{e}_k - \frac{p}{\sum_{h=1}^{2}\beta_{kh}}\end{aligned}$$

$$\begin{aligned}\overline{e}_{\text{ets}} &= e_{\text{ets}}^0 - p\sum_k\sum_j \frac{1}{\alpha_{kj}} \\ \overline{e}_{\text{ets}} &= \overline{e}_E + \overline{e}_i - e_i^0 - \sum_k\sum_{h=1}^{2} f_{kh}^0 + p\left(\frac{1}{\gamma_i} + \sum_k \frac{1}{\sum_{h=1}^{2}\beta_{kh}}\right)\end{aligned}$$

4.1.2 European regulator able to impose the national tax rates

We then have $b_{kh} = \frac{p}{\beta_{kh}}$, and equation (13) yields :

$$p = \tau_k = \frac{e^0 - \overline{e}}{\frac{1}{\gamma_i} + \sum_{k=1}^{n} \sum_{h=1}^{2} \frac{1}{\beta_{kh}}}. \tag{21}$$

4.1.3 National regulators fixing their own tax rates

Then, equation (14) yields :

$$\tau_k = \sum_{h=1}^{2} \beta_{kh} \left[e_k^0 + \sum_{h=1}^{2} f_{kh}^0 - \overline{e}_{Ek} - \left(e_{\text{ets}}^0 - \overline{e}_{\text{ets}} \right) \frac{\sum_{j=1}^{N} \frac{1}{\alpha_{kj}}}{\sum_{k=1}^{n} \sum_{j=1}^{N} \frac{1}{\alpha_{kj}}} \right]. \tag{22}$$

4.1.4 European regulator acting on the international market only

We show in the Appendix that the aggregate cost function for Europe is also quadratic, and can be written

$$K(a_E) = \frac{\gamma_E}{2} a_E^2,$$

with

$$\gamma_E = \frac{1}{\sum_k \left(\sum_j \frac{1}{\alpha_{kj}} + \frac{1}{\beta_k} \right)}. \tag{23}$$

We can then easily deduce from equation (19) the tax rates in the quadratic case :

$$\tau_k = \sum_{h=1}^{2} \beta_{kh} \left[p \frac{1}{\gamma_E} \frac{\overline{e}_{Ek}}{\overline{e}_E} - p_e \sum_{j=1}^{N} \frac{1}{\alpha_{kj}} \right]$$

p being given by the equilibrium condition on the international permits market (equation (17)) :

$$p = \frac{e^0 - \overline{e}}{\frac{1}{\gamma_i} + \frac{1}{\gamma_E}},$$

which finally allows us to obtain

$$\tau_k = \sum_{h=1}^{2} \beta_{kh} \left[\frac{e^0 - \overline{e}}{\frac{1}{\gamma_i} + \frac{1}{\gamma_E}} \frac{1}{\gamma_E} \frac{\overline{e}_{Ek}}{\overline{e}_E} - \frac{e_{\text{ets}}^0 - \overline{e}_{\text{ets}}}{\sum_{k=1}^{n} \sum_{j=1}^{N} \frac{1}{\alpha_{kj}}} \sum_{j=1}^{N} \frac{1}{\alpha_{kj}} \right]. \tag{24}$$

4.2 Simulations

4.2.1 The data

For European countries, the data used for the simulations come from the European Pollutant Emission Register[9], from the estimated NAPS for 2008-2012 and finally from the

[9] http ://www.eper.cec.eu.int

data of the POLES model. We obtain BAU emissions for 2010, for all covered sectors,the allocations per year and also the environmental constraints. Moreover, we use BAU data for no-covered sectors and others countries participating to the international emissions trading scheme. We use specifically data from the national reports submitted to the UNFCCC [10].

European covered sectors are :

– energy activities (refining, other combustion activities) ;
– production and processing of ferrous metals ;
– mineral industry (cement, glass, lime, ceramics products...) and chemical industry ;
– pulp and paper production ;
– manufacturing industries and construction.

We assume that the two representative non-covered sectors include agriculture, housing-tertiary, wastes and transports and other industrial sectors not included in the preceding list.

The two following tables give greenhouse gases emissions (in Mt CO_2 equivalent) for the base year 1990, as considered by the Kyoto Protocol, and Kyoto's targets of reduction for 2008-2012, for European countries and the Rest of the Parties.

[10] http ://www.unfccc.int

Emissions of CO_2, (Mt) and environmental target

	Emissions 1990 (Mteq CO2)	Reduction target under Kyoto Protocol (%)
European Burden Sharing Act		
AUS	54,01	-13
Baltic states	89,35	-8
BEL+LUX	120,38	-9
CZ REP	145,21	-8
DNK	51,36	-21
FIN	52,12	0
FRA	367,27	0
GER	933,9	-21
GRC	77,21	25
HUN	79,71	-6
IRE	30,38	13
ITA	404,09	-6,5
NDL	150,59	-6
POL	463	-6
PRT	39,08	27
SLK	55,36	-8
SLO-MAL-CY	23,36	-8
SPA	207,18	15
SWE	50,89	4
UK	568,88	-12,5
Burden Sharing Act		
BUL	157,09	-8
CAN	607,19	-6
EU	3963,33	-8
JAP	1246,73	-6
LIE	0,21	-8
NOR	51,96	1
NZ	73,16	0
ROM	163,6	-8
RUS FED	2360	0
SWI	48,5	-8

4.2.2 Calibration

In a general way, estimates of marginal abatement costs vary widely. The structural modelling choices impact the results. Moreover, because the article focuses on sectoral industrial abatement costs function, we need estimates of sectoral abatement costs function, ie disaggregated data. Following the IPPc framework (Fischer, 2005), four main factors contribute to variances in estimates :

– Projections of base case emissions ;

– Structural characteristics of the model (sectoral and technical detail, optimization techniques...) ;
– The climate policy regime considered ;
– The consideration of adverted climate damages.

This article uses estimates provided by POLES model (Criqui, A., Kitous, A., Stankeviciute, L., *The fundamentals of the Future International Emission Trading Systems*). POLES is a bottom-up model, with elaborated data concerning different sectors, specific level of technology and recent projections of business-as-usual emissions. We consider here five main sectors covered by EU-ETS, which are chemistry, electricity, mineral industry, industry of ferrous metals and finally other industries such as pulp and paper.We use Poles model data to determine the technological parameters included in the abatement cost function. The following table gives us the results of the calibration.

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count	ô count.
covered (α)	Chemistry	2,51	0,67	2,46	0,29	0,78	61,19	6,56	1,78	27,72	0,93	34,86	27,72	46,27
	Steel	1,64	1,48	1,36	9,53	2,72	274,79	622,63	2,35	1,60	1,48	23,09	28,54	41,55
	NMM	51,89	12,27	4,16	9,53	2,21	7,06	3,08	53,06	96,15	27,89	166,48	328,86	115,65
	Other indus.	0,31	0,44	0,24	0,12	0,38	0,95	1,69	3,49	1,51	1,31	10,38	11,35	3,50
	Electricity	0,09	0,21	0,12	0,05	0,10	0,35	0,71	0,41	3,63	0,13	1,51	1,46	0,75
non-covered (β)	Transport	0,11	0,11	0,15	0,11	0,11	0,59	0,51	0,39	0,72	0,93	1,27	2,86	1,08
	Others	0,20	0,20	0,24	0,17	0,41	1,12	2,45	0,62	8,39	0,75	2,13	9,01	3,01

These estimated parameters can vary widely because of the functional form of $C()$. The linear marginal costs induce wide differences among sectors and across countries. Actually, these parameters represent the slope of the curve. However, we can observe in a general way that those parameters reflect the empirical levels of technology. For instance, the value of electricity sector parameters are low, which implies a high level of abatement and low costs of abatement.

4.2.3 The tax rates and abatements

Following the model, we found several tax rates according to the different cases of linkage. In this section, we present the results of the different simulations. They differ according to the value of the parameter γ_i : the level of technology used in the cost abatement function for zone “Rest of the World".

First, let us consider the exogenous variables such as :

Exogenous variables

e^0_{ets}	2340,2	e_{ets}	2084,2	e_E	3645,9	e^0_E	4044,1	e_i	4568,2	e^0_i	4667,4	e^0	8711,5	e	8214	γ_i[11]	0,005

Second, we simulate the benchmark situation. We will analyze then the results compared to this situation. It is now possible to calculate the single permit price (i.e and tax rate) and then to deduce the levels of abatement for each sector in in each European country and for the “Rest of the Parties". Actually the following tables give the results in terms of abatement.

Results for benchmark case ($p = 1,28 \quad /teqCO_2$)

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count.	oth. count.
covered (a_{kj})	Chemistry	0,51	1,91	0,52	4,40	1,63	0,02	0,19	0,72	0,05	1,37	0,04	0,05	0,03
	Steel	0,78	0,86	0,94	0,13	0,47	0,00	0,00	0,54	0,80	0,86	0,06	0,04	0,03
	NMM	0,02	0,10	0,31	0,13	0,58	0,18	0,41	0,02	0,01	0,05	0,01	0,00	0,01
	Other indus.	4,11	2,88	5,36	10,54	3,39	1,34	0,76	0,37	0,85	0,97	0,12	0,11	0,36
	Electricity	13,67	6,04	10,76	23,56	12,21	3,62	1,80	3,10	0,35	9,82	0,85	0,87	1,70
non-covered (b_{kh})	Transport	11,28	11,65	8,54	12,08	11,14	2,17	2,52	3,23	1,77	1,37	1,01	0,45	1,18
	Others	6,32	6,36	5,35	7,47	3,12	1,14	0,52	2,07	0,15	1,70	0,60	0,14	0,42

On a global point of view, the results show that non-covered sectors and especially transports assume an important part of the burden. As for covered sectors, electricity fulfills the main part of the commitment, these results seem to be consistent with reality to an extent. Notice that France, United Kingdom, Germany and Spain have to make higher effort than other countries. For instance, Sweden, which is well-know as an environment friendly country would have to do q very low effort. Moreover, the situation of "hot air" in Eastern Europe countries introduce variances between levels of abatement among countries. Finally, we calculate the abatement for zone "Rest of the Parties" such as : $a_i = 255,37 MteqCO_2$.

We then examine the three potential cases of linkages, focusing on the discrepancy of abatement levels, tax rates and permit prices.

Results for a case where the European regulator is able to impose the national tax rates ($p = 1,77 \quad /teqCO_2$and $p_e = 2,36 \quad /teqCO_2$)

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count.	oth. count.
covered (a_{kj})	Chemistry	0,94	3,53	0,96	8,14	3,02	0,04	0,36	1,32	0,09	2,54	0,07	0,09	0,05
	Steel	1,44	1,60	1,74	0,25	0,87	0,01	0,00	1,01	1,48	1,60	0,10	0,08	0,06
	NMM	0,05	0,19	0,57	0,25	1,07	0,33	0,77	0,04	0,02	0,08	0,01	0,01	0,02
	Other indus.	7,60	5,34	9,91	19,52	6,28	2,48	1,40	0,68	1,57	1,80	0,23	0,21	0,68
	Electricity	25,30	11,18	19,92	43,62	22,61	6,71	3,32	5,74	0,65	18,18	1,57	1,62	3,15

Here, we observe that abatements for covered sectors are higher,and this is generated because of a higher level of the European permit price. The European permit price is derived from the equilibrium on the market explicitly written in the previous section. However, we note that for "green" countries such as Sweden, the required level of abatement is still low. Nevertheless, for countries which benefit from "hot air" such as Poland, the level of abatement is much bigger and closer to the abatement level of Italy, France... Concerning the "Rest of the Parties", the abatement is also higher, because of a different international permit price : $a_i = 353,73 MteqCO_2$. Then, we consider the influence of a higher tax rate (equal to the international permit price) on non-covered abatements. We obtain :

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count.	oth. count.
non-covered (b_{kh})	Transport	15,62	16,13	11,84	16,73	15,43	3,01	3,49	4,48	2,46	1,90	1,39	0,62	1,64
	Others	8,75	8,81	7,42	10,35	4,32	1,57	0,72	2,87	0,21	2,36	0,83	0,20	0,59

We observe that abatements are also higher compared to the benchmark case. These results show that except for electricity sector, the abatements of non-covered sectors are more important. It means that these sectors would have to provide a substantial effort to ensure the fulfilling of commitment. Here, we underline the potential distortions in terms of burden distribution among non-covered sectors and among sectors. Moreover, this is the transports sectors which would have mainly to reduce polluting emissions.

Then, we study the situation where the national European regulators do not take into account the international system. We find then different taxes for each European country to impose on non-covered sectors.

Results for a case where national regulator fix their own tax rate

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count.	oth. count.
	τ_k	2,63	1,42	2,14	5,29	5,14	0	3,23	11,58	0	0	0	0	39,74
non-covered (b_{kh})	Transport	23,19	12,96	14,32	50,02	44,83	0	6,38	29,31	0	0	0	0	36,79
	Others	13,00	7,08	8,97	30,94	12,56	0	1,32	18,75	0	0	0	0	13,20

In this case, we can observe that when tax rates are positive, then, they are in general higher compared to the previous case orto the benchmark situation. This means that in specific European countries the “old" ones, the international market benefit for non-covered sectors. Indeed, if the effort realized within the European market is too low, then, without taking into account the international market, the distortions are important among sectors and also widely among countries. For the ones, the tax rate is higher than the European permit price for the other, it is zero. Consequently, abatements for non-covered sectors vary widely. However, we notice that when levels of abatement are positive, they are important compared to the effort associated with the covered sectors. Typically, in Germany, the tax rate is very high, and the abatement is then globally higher than the total abatement realized by sectors included in EU-ETS.

Finally, we study the case where the European regulator acts on the international market. We still deduce the different tax rates, the levels of abatement for covered sectors, non-covered sectors and for the Rest of the Parties and a new international permit price.

Results for a case where a European regulator acts on the international market
$(p = 1,28 \quad /teqCO_2)$

		Gbr	Fra	Ita	Ger	Esp	Grc	Prt	B.lux	Swe	Pol	Hun	Nw count.	oth. count.
	τ_k	0	0,21	0	0	0	0	0	1,89	0	1,86	2,45	37,12	5,96
non-covered (b_{kh})	Transport	0	1,96	0	0	0	0	0	4,78	0	2,00	1,93	12,98	5,52
	Others	0	1,07	0	0	0	0	0	3,06	0	2,48	1,15	4,12	1,98

5 Concluding remarks

The main conclusion of this article is that to fulfill the international commitment, European governments will have to implement a tax rate on initially non-covered sectors. This generate distortions in terms of the burden's distribution among sectors and among countries. We observe that sectors such as electricity will have to provide n important effort, du to their high level of technology. However, concerning the non-covered sectors, results of the simulation are varying : indeed,

We briefly discuss extending the model in one direction, in particular concerning the trading restrictions. If we consider the simultaneity of EU-ETS and IET and the opportunity for European entities to trade without any restrictions within the European market, we must introduce other elements in order to make the two systems consistent. In fact, European permits can not be used for International compliance likewise the international units can't be taken into account for European compliance. These two types of units differ from their price and valor. Over the period 2008-2012, we must consider that an exchange of European units, between entities, will generate an exchange of international units between the two countries. This requires to introduce more precisely an exchange rate between the two permit prices and also to focus our attention on the countable equilibrium of the units. This could have an impact on trades within the European market and on the tax rate which can be supported by the non-covered sectors. At the international level, each European country would have to respect its commitment (determined in the European Burden Sharing Act), taking into account that all intra-Europe trades (i.e. selling or purchasing European permits) involve the same operation in terms of international units.

Another interesting extension would be to abandon the assumption of a competitive international market, and to introduce a possible market power of the European Union.

Appendix 1 : the aggregate abatement cost function

We define the aggregate abatement cost function for any abatement a as the minimum of the sum of the sectoral abatement costs functions for all European countries, given that the sum of sectoral abatements is equal to the aggregate abatement (see for instance Bréchet and Michel, 2005) :

$$K_E(a) = \begin{cases} \min \sum_k \left(\sum_j C_{kj}(a_{kj}) + \sum_h D_{kh}(b_{kh}) \right) \\ a = \sum_k \left(\sum_j a_{kj} + \sum_h b_{kh} \right). \end{cases}$$

The Lagrangian of this program reads :

$$\mathcal{L} = \sum_k \left(\sum_j C_{kj}(a_{kj}) + \sum_h D_{kh}(b_{kh}) \right) + \lambda \left[a - \sum_k \left(\sum_{j=1}^{N} a_{kj} + \sum_h b_{kh} \right) \right],$$

and the first order conditions are :

$$\begin{cases} \frac{\partial \mathcal{L}}{\partial a_{kj}} = C'_{kj}(a_{kj}) - \lambda = 0 \ \forall k, j \\ \frac{\partial \mathcal{L}}{\partial b_{kh}} = D'_{kh}(b_{kh}) - \lambda = 0 \ \forall k, h \end{cases}$$

from which we deduce

$$\lambda = C'_{kj}(a_{kj}) = D'_{kh}(b_{kh}).$$

We then obtain the sectoral abatements as functions of the Lagrange multiplier λ :

$$\begin{aligned} \widehat{a}_{kj} &= {C'_{kj}}^{-1}(\lambda) \\ \widehat{b}_{kh} &= {D'_{kh}}^{-1}(\lambda) \\ \widehat{a} &= \sum_k \left(\sum_j {C'_{kj}}^{-1}(\lambda) + \sum_h {D'_{kh}}^{-1}(\lambda) \right). \end{aligned}$$

If the sectoral abatement cost functions are homogeneous of any given degree (let's say of degree $q \geq 1$ for exposition), the marginal cost functions are homogeneous of degree $q-1$, and their inverse of degree $\frac{1}{q-1}$. We then have :

$$\widehat{a} = \lambda^{\frac{1}{q-1}} \sum_k \left(\sum_j {C'_{kj}}^{-1}(1) + \sum_h {D'_{kh}}^{-1}(1) \right),$$

hence

$$\lambda = \left[\widehat{a} \frac{1}{\sum_k \left(\sum_j {C'_{kj}}^{-1}(1) + \sum_h {D'_{kh}}^{-1}(1) \right)} \right]^{q-1},$$

and

$$\begin{aligned} K_E(\widehat{a}) &= \lambda^{\frac{q}{q-1}} \sum_k \left(\sum_j C_{kj}({C'_{kj}}^{-1}(1)) + \sum_h D_{kh}({D'_{kh}}^{-1}(1)) \right) \\ &= \widehat{a}^q \frac{\sum_k \left(\sum_j C_{kj}({C'_{kj}}^{-1}(1)) + \sum_h D_{kh}({D'_{kh}}^{-1}(1)) \right)}{\left[\sum_k \left(\sum_j {C'_{kj}}^{-1}(1) + \sum_h {D'_{kh}}^{-1}(1) \right) \right]^q}. \end{aligned}$$

In the case of quadratic cost functions ($q = 2$), this can be simply written as :

$$\begin{aligned} K_E(\widehat{a}) &= \widehat{a}^2 \frac{\sum_k \left(\sum_j \frac{1}{2} \frac{\alpha_{kj}}{(\alpha_{kj})^2} + \sum_h \frac{1}{2} \frac{\beta_{kh}}{(\beta_{kh})^2} \right)}{\left[\sum_k \left(\sum_j \frac{1}{\alpha_{kj}} + \sum_h \frac{1}{\beta_{kh}} \right) \right]^2} \\ &= \frac{1}{2} \frac{\widehat{a}^2}{\sum_k \left(\sum_j \frac{1}{\alpha_{kj}} + \sum_h \frac{1}{\beta_k} \right)} \\ &= \frac{\gamma_E}{2} \widehat{a}^2, \end{aligned}$$

with

$$\gamma_E = \frac{1}{\sum_k \left(\sum_j \frac{1}{\alpha_{kj}} + \sum_h \frac{1}{\beta_k} \right)}.$$

The aggregate cost function is quadratic, and its coefficient can be easily deduced from the coefficients of the sectoral cost functions.

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