Differentiating permits allocation across areas

Jean-Philippe Nicolaï[*], Jorge Zamorano[†‡]

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Abstract

This paper addresses the issue to differentiate permits allocation across areas. This issue is linked to the risk of relocation. We consider in this paper two different zones, a domestic one where the emissions are regulated and a second one where no environmental regulation is applied. The domestic zone is separated in two areas. The first one, located near to the border and highly subject to international competition, is called coastal zone. The second one is far away from the border and called inland zone. We show that the relocation of coastal firms abroad reduces the profit of domestic inland firms.
Keywords: Relocation; Imperfect competition; Unilateral regulation; Geographic-based subsidies, Transportation cost.

[*]ETH Zurich, Chair of Integrative Risk Management and Economics, Address: Zurichbergstrasse 18 8032 Zurich. E-mail: jnicolai@ethz.ch.

[†]Université Paris 1 Panthéon Sorbonne, Centre d'Economie de la Sorbonne, Address: 106-112 boulevard de l'Hôpital, 75647 Paris Cedex 13, France. E-mail: Jorge.Zamorano-Ford1@malix.univ-paris1.fr.

[‡]Universidad de Santiago de Chile, Departamento de Ingeniería Industrial, Address: Av. Ecuador 3769 Santiago, Chile. E-mail: jorge.zamorano.f@usach.cl.

1 Introduction

Several countries have recently implemented or intend to implement pollution permit programs. An important question related to the design of these programs is how to allocate permits to firms. The European Emission Trading Scheme (EU-ETS) is one of the main experiments and the permits allocation in this market has mainly been modified from the start.[1] In the two first phases (2005-2007 and 2008-2012), the determination of free allowances was very close: all sectors were uniformly treated and approximately all permits were given for free. However, in the third phase (2013-2020), sectors are differentiated: the power sector no longer receives free allowances while sensitive sectors, such as cement and steel, which face a significant risk of carbon leakage, may receive free allowances according to capacity-based.

This evolution was mainly driven by the will to reduce leakage and to improve the competitiveness of sensitive sectors. Carbon leakage can be interpreted in the short term as a substitution between local and foreign production and in the long-term as relocation. One part of literature which focuses on the relocation risk, shows that this latter is currently weak in Europe. Thus, Branger et al (2015)[**?**] show that relocation due to environmental motivations is very limited. Martin et al (2014)[**?**] show that currently the free allowances given are sufficient to prevent firms from relocating. However, to fulfill the European commitments of GHG reductions, the pollution caps are supposed to become more stringent and by this the permit price is supposed to increase. The question rises how to take into account the relocation risk if the permit price increases sufficiently. This paper addresses the issue to differentiate permits allocation across areas. This issue is linked to the risk of relocation which will increase with the next phases of EU-ETS if the pollution caps become more stringent.

We consider in this paper two different zones, a domestic one where the emissions are regulated and a second one where no environmental regulation is applied. The domestic zone is also separated in two areas. The first one, located near to the border and highly subject to international competition, is called coastal zone. The second one is far away from the border and called inland zone. Companies are present in all three zones. For the sake of clarity, we

[1] The EU free allowances process is exhaustively detailed in Ellerman et al (2010)[**?**].

assume that consumers are present in the inland and in the coastal zone. Each company can sell in its own market or in other markets. We assume that in each market, firms compete *à la Cournot*. First of all, we consider that the regulation has the form of a tax on emissions.

This paper justifies the protection of coastal firms. Indeed, the incentives to relocate are different across areas. For instance, if the two markets are characterized by the same demand, the coastal firms have more incentives to relocate since they are more exposed to international competition. Moreover, carbon leakage increases with relocation. Since, free allowances are a lump-sum transfer from the regulator to firms, differentiating permits across areas is a less expensive way to prevent from relocation than distribute uniformly permits for free. However, differentiation is ordinarily forbidden since it may alter competition. Here we show that, at the opposite, differentiation is helpful to the firms which do not receive free allowances.

Indeed, the relocation of coastal firms to the foreign country, reduces the profit of domestic firms. This result is surprising and has, to our knowledge, not been presented in literature so far. The intuition is the following: the necessary condition to relocate is that the permits price is sufficiently high. When coastal firms relocate in a foreign country it is then cheaper for them to sell in the inland market. Thus, the relocation makes a coastal firm more efficient and increases the competition in the inland market.

The remainder of the paper is structured as follows. Section 2 presents the modeling assumptions and analyses the economic effects of differentiating permits allocation across sectors. Section 3 concludes.

2 The Model

Assume two geographical areas, the domestic and the foreign, respectively H and F. We consider three locations for firms, inland, coastal and foreign which are representing three different markets denoted by $j = i, c, f$. The markets denoted by i and c are in the domestic area. There are n_j symmetric firms competing in each market and producing a homogenous good. To be more precise, the total number of domestic firms is $n_H = n_i + n_c$, where n_i and n_c are the number of firms competing in the inland and coastal markets.

We assume Cournot competition in each market and the demand functions are linear. Thus, they are given by:

$$P_j(Q_{j_T}) = a_j - Q_{j_T}, \qquad \forall\ j = i, c, f. \tag{1}$$

A firm is located in only one location, but it can sell in the other markets as well. A representative firm located in the market j is free to sell a part of its production to any other market. Let q_j^k be the quantity of a representative firm located in j that is sent to market k, q_j represents the total quantity produced by the representative firm located in j and Q_j is the total quantity produced in market j.[2] Let c_j be the constant marginal cost of production for each firm located in j. We consider the same marginal cost of production and the same emission intensity for both inland and coastal firms.

Transportation from one country to another is expensive and represented by a unit cost, denoted τ. We consider twice the transport cost value for the distance between inland and coastal market. The cost of transport is used to model the intensity of international competition. We assume the situation of unilateral trade, i.e. domestic firms can not export to the foreign market, meanwhile domestic markets are served by firms of both areas, because foreign firms can only export their products. In addition, the domestic area consists of inland and coastal markets between which no barriers exist. In fact, the degree of integration of markets depends on the marginal costs and the transportation cost. We present the conditions which ensure unilateral trade. These conditions, as shown in Appendix **??** are equivalent to, $c_i + 2\tau \geq \frac{n_f c_f}{n_f+1}$ and $c_c + \tau \geq \frac{n_f c_f}{n_f+1}$. It means that the marginal costs of inland and coastal firms are sufficiently high so that exporting is not profitable for domestic firms before the implementation of any environmental policy. Unilateral trade exists only if both conditions are simultaneously satisfied, and bilateral trade, when at least one condition is not satisfied.

Figure (**??**) summarizes the economic model under the unilateral trade assumption. Therein we present the three possible geographic locations as well as the two domestic markets, the

[2] Where $q_j = \sum_k q_j^k$, $Q_j = \sum_j q_j$ and $Q_{j_T} = \sum_k q_k^j \quad \forall\ j, k = i, c, f$. We use the superscript k, just to make the difference between the markets for a representative firm (i.e. $j, k = i, c, f$).

inland and the coastal. A firm located in the foreign zone only exports its production, from now on we assume that a foreign market does not exist. Finally we specify the linear distances between the emplacements or markets and their respective unit cost of transportation.

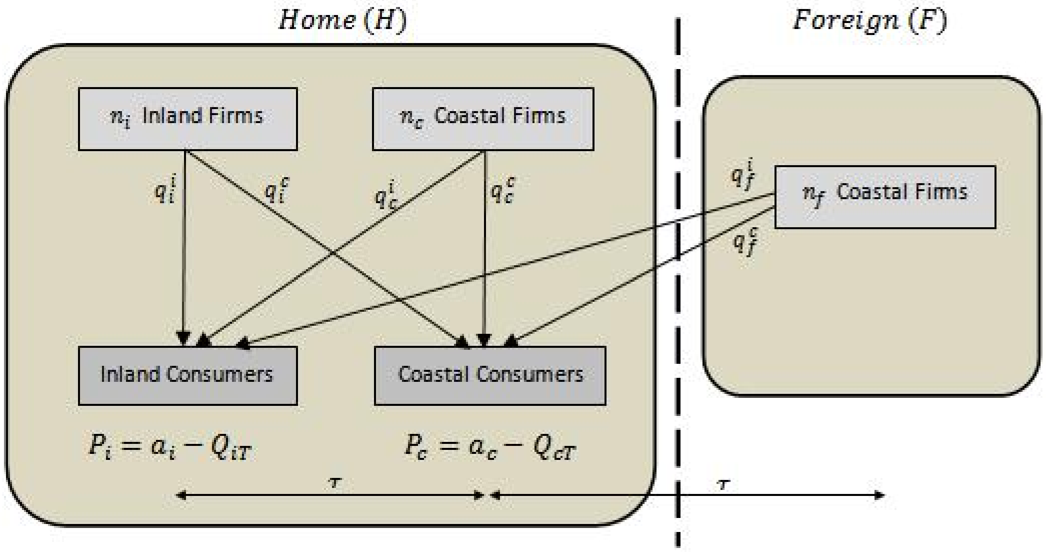

Figure 1: Summary of the Model Structure.

The profit of a representative inland firm, may be written as follows:

$$\pi_i = \quad P_i(Q_{i_T})q_i^i + P_c(Q_{c_T})q_i^c - c_i(q_i^i + q_i^c) - \tau q_i^c, \tag{2}$$

of a coastal firm:

$$\pi_c = \quad P_c(Q_{c_T})q_c^c + P_i(Q_{i_T})q_c^i - c_c(q_c^c + q_c^i) - \tau q_c^i, \tag{3}$$

And, of a foreign firm,

$$\pi_f = \quad P_c(Q_{c_T})q_f^c + P_i(Q_{i_T})q_f^i - c_f(q_f^c + q_f^i) - \tau(2q_f^i + q_f^c). \tag{4}$$

Firms maximize profits by choosing productions. Easily we obtain the first-order conditions and then we calculate the equilibrium quantities q_j^{k*}, produced by each firm for its local market as well as the productions allocated to others, i.e. the exported quantities. In Appendix **??**, we present the quantities in equilibrium and we detail calculations.

Production technology is polluting. In order to cut down pollution, the regulator implements an environmental policy in the domestic area, i.e. covering the inland and the coastal markets. To pollute firms should have a pollution permit. Let σ and μ_j be the emission tax and the emission intensity in a market j. Firms do not have access to any abatement technology to reduce emissions. The permit price modifies the marginal cost perceived by each firms in the domestic area, i.e. it modifies the equilibrium quantities. Appendix **??** characterizes the equilibrium quantities now depending to the permit price.

2.1 Relocation

Firms can relocate their production capacities to the foreign country. First, we introduce the rule of relocation and we compare the incentives to relocate among coastal and inland firms. Finally we establish the necessary conditions so that the relocation takes place.

A coastal firm has incentives to relocate its production, if, and only if, its net profit in the foreign market is higher than the current profit in the coastal market minus the relocation cost. In other words, the relocation rule for a representative firm in the coastal market is given by:

$$\pi_f(n_i, n_c - 1, n_f + 1, \sigma) - C_R \geqslant \pi_c(n_i, n_c, n_f, \sigma). \tag{5}$$

Where C_R is the fixed cost of relocation. Relocation modifies the structure of competition in each market and consequently the production of equilibrium in each market, including the foreign market. The relocation rule (**??**) depend on two different profits, π_c and π_f. $\pi_c(n_i, n_c, n_f, \sigma)$ is the profit of a coastal firm under environmental policy and $\pi_f(n_i, n_c - 1, n_f + 1, \sigma)$ is the profit of the same firm in the foreign market after the relocation takes place.

The relocation is possible for inland firms as well. The relocation rule for inland firms is given by:

$$\pi_f(n_i - 1, n_c, n_f + 1, \sigma) - C_R \geqslant \pi_i(n_i, n_c, n_f, \sigma). \tag{6}$$

Where $\pi_f(n_i - 1, n_c, n_f + 1, \sigma)$ is the foreign profit when an inland firm relocates, and $\pi_i(n_i, n_c, n_f, \sigma)$ is the current profit of an inland firm under the emission tax. We take the same fixed cost of relocation.

Until now, we have considered the fact that both, coastal and inland firms can relocate their production. We compare now the incentives to relocate for firms in each of both domestic markets.

Incentives to relocate for inland and coastal firms. We analyze in which area (inland or coastal) the incentives to relocate are the higher. This issue is crucial to determine which firms face the higher relocation risk. The following equation illustrates the conditions under which the coastal firms have higher incentives than the inland ones:

$$\pi_f(n_i, n_c - 1, n_f + 1, \sigma) - \pi_c(n_i, n_c, n_f, \sigma) \geqslant \pi_f(n_i - 1, n_c, n_f + 1, \sigma) - \pi_i(n_i, n_c, n_f, \sigma), \quad (7)$$

This condition states the case under which a coastal firm has higher incentives to relocate in the foreign country than a firm located in the inland area. Equation (**??**) leads to the following condition.

$$(a_i - a_c) + \tau(-n_i + n_c + n_f + 1) \quad \geqslant 0. \quad (8)$$

From this equation, the following Lemma is deduced.

Lemma 1. *The coastal firms have more incentives to relocate than inland firms if and only if*

$$a_i > a_c + \tau(n_i - n_c - n_f - 1). \quad (9)$$

Proof. Form equation (**??**), we get easily the expression (**??**). □

In other words, if the two markets are characterized by the same demand, the coastal firms have more incentives to relocate since they are more exposed to international competition. However, inland firms have more incentives to relocate than coastal firms if and only if the demand in the inland market is sufficiently low. This result also shows that these two areas are not altered the same way by the implementation of pollution permits. This result legitimates to differentiate permits allocation across areas.

Since in most cases, the incentives to relocate are higher for the coastal firms, we assume for the remaining that coastal firms are more willing to relocate and we focus now on the necessary conditions for coastal firms to relocate.

Coastal firms' relocation. As we have defined previously, a coastal firm relocates if:

$$\pi_f(n_i, n_c - 1, n_f + 1, \sigma) - C_R \geqslant \pi_c(n_i, n_c, n_f, \sigma), \tag{10}$$

Knowing that $\pi_f(n_i, n_c - 1, n_f + 1, \sigma) = q_f^i(\sigma, 1)^2 + q_f^c(\sigma, 1)^2$ and $\pi_c(n_i, n_c, n_f, \sigma) = q_c^i(\sigma)^2 + q_c^i(\sigma)^2$. We rewrite the equation (**??**) as:

$$q_f^i(\sigma, 1)^2 + q_f^c(\sigma, 1)^2 - q_c^i(\sigma)^2 - q_c^c(\sigma)^2 \geqslant C_R, \tag{11}$$

$$\left(q_f^i(\sigma, 1) - q_c^i(\sigma)\right)\left(q_f^i(\sigma, 1) + q_c^i(\sigma)\right) + \left(q_f^c(\sigma, 1) - q_c^c(\sigma)\right)\left(q_f^c(\sigma, 1) + q_c^c(\sigma)\right) \geqslant C_R. \tag{12}$$

Focusing on the differences $q_f^i(\sigma, 1) - q_c^i(\sigma)$ and $q_f^c(\sigma, 1) - q_c^c(\sigma)$, we calculate them using the quantities presented in Appendix **??**. The two differences are equal to $-\phi_c(\sigma)(n_i + n_c + n_f)$. Let $\phi_c(\sigma)$ denote the difference of marginal cost in the foreign and coastal markets over the total number of firms in both areas. In other words, $\phi_c(\sigma) = \frac{c_f + \tau - c_c - \mu_c \sigma}{(n_i + n_c + n_f + 1)}$. We rewrite the condition (**??**) as:

$$-\phi_c(\sigma)(n_i + n_c + n_f)\left(q_f^i(\sigma, 1) + q_f^c(\sigma, 1) + q_c^i(\sigma) + q_c^c(\sigma)\right) \geqslant C_R, \tag{13}$$

$$-\phi_c(\sigma)(n_i + n_c + n_f)\left(q_f(\sigma, 1) + q_c(\sigma)\right) \geqslant C_R, \tag{14}$$

where $n_i + n_c + n_f$ is the total number of firms, $q_f(\sigma, 1)$ is the total production of a foreign firm after the relocation of a firm took place from the coastal to the foreign market, and $q_c(\sigma)$ is the total firm's production in the coastal zone.

The following Lemma gives the conditions under which the relocation is profitable for one firm.

Lemma 2. *If a coastal firm relocates to a foreign country, the permit price is higher than* $\bar{\sigma} = \frac{c_f + \tau - c_c}{\mu_c}$.

Proof. If relocation occurs, it means that the left side of the equation (**??**) is strictly positive. Since the expressions $n_i + n_c + n_f$ and $q_f(\sigma, 1) + q_c(\sigma)$ are always positive, it induces that:

$$\phi_c(\sigma) = \frac{c_f + \tau - c_c - \mu_c \sigma}{(n_i + n_c + n_f + 1)} < 0. \tag{15}$$

Thus, we deduce that for a $\sigma > \bar{\sigma} = \frac{c_f + \tau - c_c}{\mu_c}$, then relocation occurs. □

This Lemma shows that for low values of the permit price, relocation does not occur. Thus, for the next phases of the EU-ETS relocation may occur, if the permit price gets higher than this threshold.

2.2 Effects of the relocation on carbon leakage

We analyze the effects of relocation on carbon leakage. Indeed, establishing unilaterally a market for permits or a tax for emissions in one area, has the effect of generating a loss of competitiveness for companies in the same area, in our case the domestic area. An indirect consequence of the loss of domestic competitiveness is the increase of emissions in countries who are not subject of environmental regulation and who are exporters in the regulated area. This is called "Carbon Leakage". Carbon leakage in the foreign country is defined as the difference between issued pollution under an implemented domestic emissions tax (considering as possible effect the relocation of l domestic firms), and issued pollution, when no environmental regulation is considered in the area (Business-as-usual).[3] These can result from a substitution of sold goods, but also from longer-term relocation.

[3]More accurate is the definition given by the UNFCCC, Carbon Leakage is the increase of emissions in countries that have not ratified Annex B of the Kyoto Protocol following the implementation of reductions in the concerned countries.

Therefore we define the carbon leakage in the foreign area as the difference of emissions under environmental regulation with relocation risk and the emissions under BAU scenario:

$$L(\sigma,l) = \quad E_f(\sigma,l) - E_f(\sigma=0), \tag{16}$$

$$L(\sigma,l) = \quad \mu_f Q_f^*(\sigma,l) - \mu_f Q_f^*(\sigma=0), \tag{17}$$

Now considering that the foreign firms are symmetric and the number of competitors is modified by the relocation, we can rewrite the equation above using the property of linearity as:

$$L(\sigma,l) = \quad \mu_f(n_f+l)q_f^*(\sigma,l) - \mu_f n_f q_f^*(\sigma=0), \tag{18}$$

$$L(\sigma,l) = \quad \mu_f n_f \left(q_f^*(\sigma,l) - q_f^*(\sigma=0)\right) + \mu_f l q_f^*(\sigma,l), \tag{19}$$

$$L(\sigma,l) = \quad \mu_f n_f \left(q_f^*(\sigma) - q_f^*(\sigma=0)\right) + \mu_f l \left(q_f^*(\sigma,l) + 2n_f\phi_c\right). \tag{20}$$

From the equations above we can obtain a general expression for the leakage, in which we clearly distinguish two effects. The first effect due to the implementation of an emission tax and the second effect produced by the relocation of l firms towards a foreign country.

Using the equilibrium quantities presented in the Appendix **??**, we formalize the leakage function in the following Lemma.

Lemma 3. *The carbon leakage under environmental regulation and relocation of l firms is compound of two effects: the substitution effect and the relocation effect:*

$$L(\sigma,l) = \underbrace{\frac{2n_f\mu_f\sigma(n_i\mu_i+n_c\mu_c)}{n_i+n_c+n_f+1}}_{Substitution \quad Effect} + \underbrace{l\mu_f\left(q_f^*(\sigma,l)+2n_f\phi_c\right)}_{Relocation \quad Effect}. \tag{21}$$

We can separate the leakage function in two components, the first expression shows the effect resulting from the environmental regulation, and the second expression shows the effect due to the l firms relocation. The *Substitution Effect* is always a positive constant and does not depend on the number of firms that relocate. However, the *Relocation Effect* is a positive and non-monotonically increasing function of l, but with a **decreasing marginal increase**, i.e. for each firm that relocates its production, the increased effect on carbon leakage is less significant.[4] Therefore, the effect of relocation is important in the carbon leakage and it increases when the relocation rises.

2.3 The effect of relocation on domestic firms' profits

Differentiation is ordinarily forbidden since it may alter competition. Here we show that, at the opposite, differentiation is helpful to the firms which do not receive free allowances. Thus, we discuss the effect on the domestic firms' profits of coastal firms relocation. We proceed as follows, first we present the profits in equilibrium considering the properties of linearity of the quantities and then we analyze the effects of relocation.

At equilibrium the profit of domestic firms is given by the sum of the square of each produced quantity. Let us start by analyzing the inland firms, when l coastal firms relocate their production, the profit of an inland firm is given by:

$$\pi_i(\sigma, l) = \quad q_i^{i*}(\sigma, l)^2 + q_i^{c*}(\sigma, l)^2. \tag{22}$$

Where $q_i^{i*}(\sigma, l)$ and $q_i^{c*}(\sigma, l)$ are the inland quantities produced when l coastal firms are relocated. We can rewrite the above equation using the linearity property of equilibrium quantities. First, we can separate the relocation effect and write the equilibrium quantities under an emission tax and the relocation of l coastal firms as the addition of the quantities under environmental regulation plus the relocation effect, i.e. $q_i^i(\sigma, l) = q_i^i(\sigma) + l\phi_c$ and $q_i^c(\sigma, l) = q_i^c(\sigma) + l\phi_c$. Replacing the quantities in equation (**??**) we obtain a new profit equation as:

$$\pi_i(\sigma, l) = \quad (q_i^{i*}(\sigma) + l\phi_c)^2 + (q_i^{c*}(\sigma) + l\phi_c)^2. \tag{23}$$

As we are searching for the impact of relocation on the benefits of coastal firms, we derive

[4] Mathematically we can say, $\frac{\partial R.E.}{\partial l} > 0$ and $\frac{\partial^2 R.E.}{\partial l^2} < 0$

the profit function with respect to l at the equilibrium, and we get, that:

$$\frac{\partial \pi_i(\sigma,l)}{\partial l} = \quad 2\phi_c \left(q_i^{i*}(\sigma,l) + q_i^{c*}(\sigma,l) \right). \tag{24}$$

Where $q_i^{i*}(\sigma,l) + q_i^{c*}(\sigma,l)$ is the total positive production of a representative inland firm after the relocation of l coastal firms.

By Lemma **??**, we know, that the necessary condition to ensure the relocation, is that ϕ_c is negative, i.e. the effect of relocation l coastal firms has a negative effect on the profit of each inland firm.

We can establish the following proposition.

Proposition 1. *The profits of the firms in the inland zone decrease with the relocation of firms from the coastal zone to the foreign country.*

Proof. From equation (**??**), we get easily that $\frac{\partial \pi_i(\sigma,l)}{\partial l} < 0$. □

The same effect on profits is present in the coastal market. First, we present the profit function of a coastal firm and second, considering the same properties and assumptions, we observe the same effect on coastal profits, when l coastal firms relocate their production.

$$\pi_c(\sigma,l) = \quad (q_c^{i*}(\sigma) + l\phi_c)^2 + (q_c^{c*}(\sigma) + l\phi_c)^2, \tag{25}$$

$$\frac{\partial \pi_c(\sigma,l)}{\partial l} = \quad 2\phi_c(q_c^{i*}(\sigma,l) + q_c^{c*}(\sigma,l)). \tag{26}$$

Knowing that $q_c^{i*}(\sigma,l) + q_c^{c*}(\sigma,l)$ is the total production of a representative coastal firm when l firms have been relocated.

Similarly to the inland case, we can establish the following proposition.

Proposition 2. *The profits of the remaining firms in the coastal zone decrease with the relocation of firms from the coastal zone to the foreign country.*

Proof. From equation (**??**), we get easily that $\frac{\partial \pi_c(\sigma,l)}{\partial l} < 0$. □

To conclude, these two propositions show that relocation has a negative effect on the firms, who still produce in their home country. When coastal firms relocate in a foreign country, they still can sell in the inland zone, and it is then cheaper for them to sell in the inland market. Thus, the relocation makes a coastal firm more efficient and increases the competition in the inland market.

2.4 Robustness

We study the robustness of the results previously shown.

2.4.1 Different transport costs

We relax now the assumption that the unit transport costs between the inland and the coastal market and the cost between the coastal and the foreign market are identical. We show that it affects the incentives to relocate and the necessary condition to relocate. Let τ_1 be the unit transport costs between the inland and coastal market and τ_2 between the coastal and foreign market. In Appendix **??**, the calculations are detailed in extensive. Now, assuming different transportation costs, we analyze in which domestic area the incentives for relocation are higher. The following equation illustrates the condition under which a coastal firm has higher incentives to relocate, and it is equal to $(a_i - a_c) + \tau_1(-n_i + n_c + n_f + 1) > 0$. Now, the comparison between the incentives in the two areas depends only on the value of the unit transport cost between them. However, the new permit price threshold depends on τ_2 and this threshold is increasing with the unit transportation cost from the coastal to the foreign zone. Thus, the permit price σ should be higher than $\bar{\sigma} = \frac{c_f + \tau_2 - c_c}{\mu_c}$, so that the relocation takes place. To conclude, the incitations in the domestic zone rest the same and the profits of the remaining domestic firms are affected by the relocation.

2.4.2 Demand in the foreign country

We relax now the assumption that there is no demand in the foreign area. This assumption changes the necessary condition to relocate and the condition under which the relocation makes the remaining firms' profits decrease.

Let $P_f(Q_{f_T}) = a_f - Q_{f_T}$ be the linear demand in the foreign market, where a_f is the foreign market size and Q_{f_T} represents the amount of trade in it. We assume that domestic firms do not sell in the foreign market. Let q_f^{f*} be the equilibrium quantity produced by a representative foreign firm and sold in the foreign market. When the number of foreign firms is n_f, the individual production is equal to $q_f^{f*}(n_f) = \frac{a_f - c_f}{n_f+1}$ in a business as usual scenario.

First of all, we compare the incentives that firms have in both, inland and coastal markets, and we show that relaxing this assumption does not modify the differences between the incentives. Considering equation (**??**) again, we observe that on both sides the foreign profits increase by the same amount of $q_f^{f*}(n_f+1)^2$, due to the modification of the quantities of foreign firms by the new demand in the country. In fact, the introduction of demand in the foreign market does not modify the comparison of incentives.

However, the criterion for the taking place of the relocation changes and it is affected by the produced quantity and sold in the foreign market $q_f^{f*}(n_f+1)$, note that this value is independent of σ. As we noted previously, we can rewrite the new relocation rules as:

$$-\phi_c(\sigma)(n_i + n_c + n_f)\left(q_f(\sigma, 1) + q_c(\sigma)\right) \geq C_R - q_f^f(n_f+1)^2. \tag{27}$$

Let $\tilde{\sigma}$ be the new threshold value which makes $\phi_c(\tilde{\sigma}) = 0$. The relocation occurs when the left side of the equation (**??**) is positive. For this purpose $\phi_c(\sigma)$ must be negative, i.e. $\phi_c(\sigma) = \frac{c_f + \tau - c_c - \mu_c \sigma}{(n_i + n_c + n_f + 1)} < 0$. In fact, with a permit price higher than $\tilde{\sigma}$, the relocation takes place. From equation (**??**), and at the same time considering that $C_R - q_f^f(n_f+1)^2 > 0$, we observe that relocation may occur for smaller values of σ, close to $\tilde{\sigma}$, i.e in this case the permit price that ensures the relocation is smaller than the permit price under the assumption presented in Lemma **??**.

However, the conditions in the domestic markets are unchanged and the condition under which the decrease of the remaining firms' profits by relocation still remains the same.

2.4.3 Relocation of inland firms

We assume that the inland firms have the highest incentives to relocate. And also, that the relocation of inland firms affects the inland and coastal profits as a direct consequence of the loss of competitiveness. The individual domestic profits are seriously affected by the relocation. From the equations of profits of inland and coastal firms we obtain: $\frac{\partial \pi_i(\sigma,l)}{\partial l} < 0$ and $\frac{\partial \pi_c(\sigma,l)}{\partial l} < 0$.

Finally, considering that relocation for inland firms occur the profits of the remaining firms in domestic zone are affected in the same way.

3 Discussion and concluding remarks

This paper justifies the protection of coastal firms and shows that the incentives to relocate are different across areas. However, differentiation is ordinarily forbidden since it may alter competition. This paper demonstrates that, at the opposite, differentiation is helpful to the firms which do not receive free allowances. Indeed, the relocation of coastal firms to the foreign country, reduces the profit of domestic firms. Thus, the relocation makes a coastal firm more efficient and increases the competition in the inland market. This effect justifies legally to differentiate firms accross areas.

Nevertheless, another difficulty is how to to differentiate permits allocation accross areas. Two various approachs may be used: to determine areas and to determine a formula according to various characteristics. A formula may be more equitable. Indeed, definig some areas requires obviously some arbitrary decisions. However, to calculate this formula the information necessary are relatively important.

This paper has show that the two main ingredients are transportation costs and the demand size in the different markets. The transportation cost may differ drastically accross sectors and accross the way to transport goods. For instance, the transportation of cement is extremelly expensive by road and relatively cheap by sea. These differences go towards different treatments accross sectors, which is allowed in the EU, as it is done for third phase of EU-ETS (different treatment for the electricity sector as for the steel and cement sectors).

Moreover, the demand size in each market play a crucial role and should be taken into account to define the relevant areas. An empirical analysis to determine in Europe the different incentives to relocate would be a promising project.

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Appendix

A Condition to ensure the existence of unilateral trade between geographical areas

Now we present the condition that ensures the existence of unilateral trade. We need to ensure that there is no production shipped abroad from the domestic area, i.e. $q_i^{f*}(\sigma = 0) \leq 0$ and $q_c^{f*}(\sigma = 0) \leq 0$.

We calculate these quantities from the equilibrium in a business-as-usual case, and we get:

$$q_i^{f*} = \frac{a_f - (n_c + n_f + 1)c_i + n_c c_c + n_f c_f - (n_c + 2n_f + 2)\tau}{(n_i + n_c + n_f + 1)}, \tag{28}$$

$$q_c^{f*} = \frac{a_f + n_i c_i - (n_i + n_f + 1)c_c + n_f c_f - (-n_i + n_f + 1)\tau}{(n_i + n_c + n_f + 1)}. \tag{29}$$

Thus, the conditions that ensures the existence of unilateral trade are given by:

$$\frac{a_f - (n_c + n_f + 1)c_i + n_c c_c + n_f c_f - (n_c + 2n_f + 2)\tau}{(n_i + n_c + n_f + 1)} \leqslant 0, \tag{30}$$

$$\frac{a_f + n_i c_i - (n_i + n_f + 1)c_c + n_f c_f - (-n_i + n_f + 1)\tau}{(n_i + n_c + n_f + 1)} \leqslant 0. \tag{31}$$

We deduce then that the conditions are equivalent to:

$$a_f + n_f c_f + n_c(c_c + \tau) - (n_c + n_f + 1)(c_i + 2\tau) \leqslant 0, \tag{32}$$

$$a_f + n_f c_f - (n_i + n_f + 1)(c_c + \tau) + n_i(c_i + 2\tau) \leqslant 0. \tag{33}$$

Unilateral trade exist only if both conditions (**??**) and (**??**), are satisfied simultaneously. Then, the conditions over the marginal cost for inland and coastal firms to ensure unilateral trade:

$$c_i + 2\tau \quad \geqslant \frac{a_f + n_f c_f}{n_f + 1}, \tag{34}$$

$$c_c + \tau \quad \geqslant \frac{a_f + n_f c_f}{n_f + 1}. \tag{35}$$

B Firms' quantities

B.1 Firms' quantities and profits at business as usual

The equilibrium quantities are given by:

$$q_i^{i*} = \frac{a_i - (n_c + n_f + 1)c_i + n_c c_c + n_f c_f + (n_c + 2n_f)\tau}{(n_i + n_c + n_f + 1)}, \tag{36}$$

$$q_i^{c*} = \frac{a_c - (n_c + n_f + 1)c_i + n_c c_c + n_f c_f - (n_c + 1)\tau}{(n_i + n_c + n_f + 1)}, \tag{37}$$

$$q_c^{i*} = \frac{a_i + n_i c_i - (n_i + n_f + 1)c_c + n_f c_f - (n_i - n_f + 1)\tau}{(n_i + n_c + n_f + 1)}, \tag{38}$$

$$q_c^{c*} = \frac{a_c + n_i c_i - (n_i + n_f + 1)c_c + n_f c_f + (n_i + n_f)\tau}{(n_i + n_c + n_f + 1)}, \tag{39}$$

$$q_f^{i*} = \frac{a_i + n_i c_i + n_c c_c - (n_i + n_c + 1)c_f - (2n_i + n_c + 2)\tau}{(n_i + n_c + n_f + 1)}, \tag{40}$$

$$q_f^{c*} = \frac{a_c + n_i c_i + n_c c_c - (n_i + n_c + 1)c_f - (n_c + 1)\tau}{(n_i + n_c + n_f + 1)}. \tag{41}$$

The profits are given by:

$$\pi_i \quad = (q_i^{i*})^2 + (q_i^{c*})^2, \tag{42}$$

$$\pi_c \quad = (q_c^{i*})^2 + (q_c^{c*})^2, \tag{43}$$

$$\pi_f \quad = (q_f^{i*})^2 + (q_f^{c*})^2. \tag{44}$$

B.2 Firms' quantities under environmental regulation without relocation

$$q_i^{i*}(\sigma) = \frac{a_i-(n_c+n_f+1)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)+n_f c_f+(n_c+2n_f)\tau}{(n_i+n_c+n_f+1)}, \tag{45}$$

$$q_i^{c*}(\sigma) = \frac{a_c-(n_c+n_f+1)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)+n_f c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}, \tag{46}$$

$$q_c^{i*}(\sigma) = \frac{a_i+n_i(c_i+\sigma\mu_i)-(n_i+n_f+1)(c_c+\sigma\mu_c)+n_f c_f-(n_i-n_f+1)\tau}{(n_i+n_c+n_f+1)}, \tag{47}$$

$$q_c^{c*}(\sigma) = \frac{a_c+n_i(c_i+\sigma\mu_i)-(n_i+n_f+1)(c_c+\sigma\mu_c)+n_f c_f+(n_i+n_f)\tau}{(n_i+n_c+n_f+1)}, \tag{48}$$

$$q_f^{i*}(\sigma) = \frac{a_i+n_i(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)-(n_i+n_c+1)c_f-(2n_i+n_c+2)\tau}{(n_i+n_c+n_f+1)}, \tag{49}$$

$$q_f^{c*}(\sigma) = \frac{a_c+n_i(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)-(n_i+n_c+1)c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}. \tag{50}$$

B.3 Firms' quantities under environmental regulation with Coastal Relocation

$$q_i^{i*}(\sigma,l) = \frac{a_i-(n_c+n_f+1)(c_i+\sigma\mu_i)+(n_c-l)(c_c+\sigma\mu_c)+(n_f+l)c_f+(n_c+2n_f+l)\tau}{(n_i+n_c+n_f+1)}, \tag{51}$$

$$q_i^{c*}(\sigma,l) = \frac{a_c-(n_c+n_f+1)(c_i+\sigma\mu_i)+(n_c-l)(c_c+\sigma\mu_c)+(n_f+l)c_f-(n_c-l+1)\tau}{(n_i+n_c+n_f+1)}, \tag{52}$$

$$q_c^{i*}(\sigma,l) = \frac{a_i+n_i(c_i+\sigma\mu_i)-(n_i+n_f+l+1)(c_c+\sigma\mu_c)+(n_f+l)c_f-(n_i-n_f-l+1)\tau}{(n_i+n_c+n_f+1)}, \tag{53}$$

$$q_c^{c*}(\sigma,l) = \frac{a_c+n_i(c_i+\sigma\mu_i)-(n_i+n_f+l+1)(c_c+\sigma\mu_c)+(n_f+l)c_f+(n_i+n_f+l)\tau}{(n_i+n_c+n_f+1)}, \tag{54}$$

$$q_f^{i*}(\sigma,l) = \frac{a_i+n_i(c_i+\sigma\mu_i)+(n_c-l)(c_c+\sigma\mu_c)-(n_i+n_c-l+1)c_f-(2n_i+n_c-l+2)\tau}{(n_i+n_c+n_f+1)}, \tag{55}$$

$$q_f^{c*}(\sigma,l) = \frac{a_c+n_i(c_i+\sigma\mu_i)+(n_c-l)(c_c+\sigma\mu_c)-(n_i+n_c-l+1)c_f-(n_c-l+1)\tau}{(n_i+n_c+n_f+1)}. \tag{56}$$

B.4 Quantities under Inland Relocation

$$q_i^{i*}(\sigma, l) = \frac{a_i-(n_c+n_f+l+1)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)+(n_f+l)c_f+(n_c+2n_f+2l)\tau}{(n_i+n_c+n_f+1)}, \tag{57}$$

$$q_i^{c*}(\sigma, l) = \frac{a_c-(n_c+n_f+l+1)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)+(n_f+l)c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}, \tag{58}$$

$$q_c^{i*}(\sigma, l) = \frac{a_i+(n_i-l)(c_i+\sigma\mu_i)-(n_i+n_f+1)(c_c+\sigma\mu_c)+(n_f+l)c_f-(n_i-n_f-2l+1)\tau}{(n_i+n_c+n_f+1)}, \tag{59}$$

$$q_c^{c*}(\sigma, l) = \frac{a_c+(n_i-l)(c_i+\sigma\mu_i)-(n_i+n_f+1)(c_c+\sigma\mu_c)+(n_f+l)c_f+(n_i+n_f)\tau}{(n_i+n_c+n_f+1)}, \tag{60}$$

$$q_f^{i*}(\sigma, l) = \frac{a_i+(n_i-l)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)-(n_i-l+n_c+1)c_f-(2n_i-2l+n_c+2)\tau}{(n_i+n_c+n_f+1)}, \tag{61}$$

$$q_f^{c*}(\sigma, l) = \frac{a_c+(n_i-l)(c_i+\sigma\mu_i)+n_c(c_c+\sigma\mu_c)-(n_i-l+n_c+1)c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}. \tag{62}$$

B.5 Firms' quantities at business as usual with different transportation costs

$$q_i^{i*} = \frac{a_i-(n_c+n_f+1)c_i+n_cc_c+n_fc_f+(n_c+n_f)\tau_1+n_f\tau_2}{(n_i+n_c+n_f+1)}, \tag{63}$$

$$q_i^{c*} = \frac{a_c-(n_c+n_f+1)c_i+n_cc_c+n_fc_f-(n_c+n_f+1)\tau_1+n_f\tau_2}{(n_i+n_c+n_f+1)}, \tag{64}$$

$$q_c^{i*} = \frac{a_i+n_ic_i-(n_i+n_f+1)c_c+n_fc_f-(n_i+1)\tau_1+n_f\tau_2}{(n_i+n_c+n_f+1)}, \tag{65}$$

$$q_c^{c*} = \frac{a_c+n_ic_i-(n_i+n_f+1)c_c+n_fc_f+n_i\tau_1+n_f\tau_2}{(n_i+n_c+n_f+1)}, \tag{66}$$

$$q_f^{i*} = \frac{a_i+n_ic_i+n_cc_c-(n_i+n_c+1)c_f-(n_i+1)\tau_1-(n_i+n_c+1)\tau_2}{(n_i+n_c+n_f+1)}, \tag{67}$$

$$q_f^{c*} = \frac{a_c+n_ic_i+n_cc_c-(n_i+n_c+1)c_f+n_i\tau_1-(n_i+n_c+1)\tau_2}{(n_i+n_c+n_f+1)}. \tag{68}$$

B.6 Firms' quantities at business as usual with demand in the foreign country

$$q_i^{i*} = \frac{a_i-(n_c+n_f+1)c_i+n_c c_c+n_f c_f+(n_c+2n_f)\tau}{(n_i+n_c+n_f+1)}, \quad (69)$$

$$q_i^{c*} = \frac{a_c-(n_c+n_f+1)c_i+n_c c_c+n_f c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}, \quad (70)$$

$$q_c^{i*} = \frac{a_i+n_i c_i-(n_i+n_f+1)c_c+n_f c_f-(n_i-n_f+1)\tau}{(n_i+n_c+n_f+1)}, \quad (71)$$

$$q_c^{c*} = \frac{a_c+n_i c_i-(n_i+n_f+1)c_c+n_f c_f+(n_i+n_f)\tau}{(n_i+n_c+n_f+1)}, \quad (72)$$

$$q_f^{i*} = \frac{a_i+n_i c_i+n_c c_c-(n_i+n_c+1)c_f-2(n_i+n_c+1)\tau}{(n_i+n_c+n_f+1)}, \quad (73)$$

$$q_f^{c*} = \frac{a_c+n_i c_i+n_c c_c-(n_i+n_c+1)c_f-(n_c+1)\tau}{(n_i+n_c+n_f+1)}, \quad (74)$$

$$q_f^{f*} = \frac{a_f-c_f}{1+n_f}. \quad (75)$$

C Inland Relocation's Rule.

$$\pi_f(n_i-1, n_c, n_f+1, \sigma) - C_R \geq \pi_i(n_i, n_c, n_f, \sigma), \quad (76)$$

We know that $\pi_f(n_i-1, n_c, n_f+1, \sigma) = q_f^i(\sigma,1)^2 + q_f^c(\sigma,1)^2$ and $\pi_i(n_i, n_c, n_f, \sigma) = q_i^i(\sigma)^2 + q_i^c(\sigma)^2$. We rewrite the equation (**??**) as:

$$q_f^i(\sigma,1)^2 + q_f^c(\sigma,1)^2 - q_i^i(\sigma)^2 - q_i^c(\sigma)^2 \geqslant C_R, \quad (77)$$

$$\left(q_f^i(\sigma,1) - q_i^i(\sigma)\right)\left(q_f^i(\sigma,1) + q_i^i(\sigma)\right) + \left(q_f^c(\sigma,1) - q_i^c(\sigma)\right)\left(q_f^c(\sigma,1) + q_i^c(\bar{\sigma})\right) \geqslant C_R. \quad (78)$$

We calculate the differences $q_f^i(\sigma,1) - q_i^i(\sigma)$ and $q_f^c(\sigma,1) - q_i^c(\sigma)$, in both cases are equals to $\phi_i(\sigma)(n_i+n_c+n_f)$. Where $\phi_i(\sigma)$ is equal to $\frac{c_f+2\tau-c_i-\sigma\mu_i}{(n_i+n_c+n_f+1)}$.

We rewrite the equation (**??**) as:

$$-\phi_i(\sigma)(n_i+n_c+n_f)\left(q_f^i(\sigma,1) + q_i^i(\sigma) + q_f^c(\sigma,1) + q_i^c(\sigma)\right) \geqslant C_R, \quad (79)$$

$$-\phi_i(\sigma)(n_i+n_c+n_f)\left(q_f(\sigma,1) + q_i(\sigma)\right) \geqslant C_R, \quad (80)$$

Where $n_i+n_c+n_f$ represent the total number of firms, $q_f(\sigma,1)$ is the total production of a foreign firm after the relocation took place from the inland to the foreign market, and $q_i(\sigma)$ is the total firm's production in the inland market.

To encourage the relocation, the left hand of the equation (**??**) must be positive. This occurs when $\phi_i(\sigma)$ is strictly negative.

$$\phi_i(\sigma) = \frac{c_f + 2\tau - c_i - \bar{\sigma}\mu_i}{(n_i + n_c + n_f + 1)} < 0, \tag{81}$$

Thus, we deduce that for a $\sigma > \bar{\sigma} = \frac{c_f+2\tau-c_i}{\mu_i}$ the relocation from the inland to the foreign zone may be accur.