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Carbon Leakage and Capacity-Based Allocations.
Is the EU right?

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Abstract

Two main approaches have been implemented in regional CO₂ markets to address competitiveness and carbon leakage: output based allocation (Australia, California, New Zealand) and capacity based allocation (EU). This paper characterizes the best policy, given that auctioning with border adjustment is excluded. A simple model is used in which the regional demand is subject to business cycles, and the import pressure depends on the demand level and capacity constraints. A combination of output and capacity based allocation is proved to be the optimal second best policy. The EU scheme for 2013-2020 is discussed, using cement as a case study.

JEL-Code: D240, L130, H230, L740.

Keywords: cap and trade, output based allocation, subsidization of capacity, climate policy, carbon leakage, competitiveness.

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1 Introduction

In the design of the European emission trading scheme (EU-ETS), allocation mechanism has been identified as a controversial subject. For instance, the use of grandfathering allocation has been essentially seen as a pragmatic tool to mitigate industry opposition while having no impact on abatement policies. But, economic studies have pointed out that the actual level of allocation has been much too high if a profit neutrality objective were the implicit constraint (see for instance Bovenberg et al. 2001, Smale et al., 2006). Another example of controversy is related to the use of the new entrant and closure provisions, in which free allocations are based on investment decisions. This provision has been seen as a pragmatical way to provide flexibility with respect to demand uncertainty. However, economic studies have argued that such a provision has created uneconomical investment subsidization of carbon intensive electricity plants (Ellerman, 2008).

Nowadays a number of countries have set up their own national or regional ETS schemes or ambition to do so (Australia, California, China, India, New Zealand...). The EU will implement a new scheme for the period 2013–2020. In all these designs, the allocation mechanism has been or will be an important factor of success for their actual implementation (see Hood, 2010 for a review of existing and proposed ETS worldwide, and a presentation of their respective design). This attention comes from competitiveness and leakage issues and their implications in terms of potential profit loss, employment, reduced environmental impact due to the transfer of emissions from one country to the other. Indeed, the implementation or the lack of implementation of these national ETS will generate major differences in the carbon prices worldwide. Internationally traded carbon intensive sectors may be significantly affected by these differences resulting in production and investment transfers from high carbon price countries to low carbon price ones. While border adjustment mechanism may limit these competitive distortions, they are seen by many emerging countries as indirect protectionist measures incompatible with the philosophy of the World Trade Organization (Wooders and Cosbey, 2010). The design of an appropriate allocation mechanism is a way to circumvent this political constraint. Two main approaches have been proposed: output based allocation (implemented in New Zealand, and to be implemented in Australia and California), capacity based allocation (implemented in the EU).

Under an output based allocation a plant will receive free allocations based on its production times the industry benchmark. Such a scheme has two positive impacts: firstly abatement incentives remain, secondly by reducing the perceived cost of home production it preserves a level playing field with foreign production unaffected by a carbon price. However, it is done at the cost of eliminating the output price signal for consumers and the negative impacts come from the fact that there may be excessive consumption of products that benefit from the scheme. Several authors have analyzed output-based allocation scheme. Böringer and Lange (2005) discussed its advantages compared to an emissions-based allocation rule. Fisher and Fox (2012) analyze its effectiveness to address the issue of leakage and competitiveness. Quirion (2009) provides a survey of this literature.

A capacity based allocation would subsidize equally existing capacities and new capacities based on an industry benchmark, but without reference to actual production. For existing

capacities it essentially amounts to a grandfathering scheme, except that the allowances are lost in case the plant is definitively closed. For new capacities it amounts to investment subsidies. Relocation of industry is mitigated while the price signal remains in place. The overall impact on import is a priori ambiguous. The economics of such a scheme has firstly been investigated by Ellerman (2008) in the context of the EU electricity market. The analysis is a positive one, which points out that it may have resulted in excess investment in carbon intensive electricity production. Ellerman also discusses the possible impact of this excessive investment for the electricity price giving due consideration to peak and off peak periods. Other authors have also discussed how the EU allocation mechanism has determined the energy mix in the electricity industry (see Neuhoff et al. 2006, Zhao et al. 2010, Golombeck et al., 2011).

While there has been much discussion of the relative merits of output based mechanism versus border trade adjustments (Monjon and Quirion, 2011a), the analysis of capacity based allocation has remained so far quite limited. Since the electricity sector is not exposed to international competition and potential leakage, the use of capacity based allocation can only be distortive in that sector.

The objective of the paper is to discuss the question of the optimal policy from a normative point of view in the context of international competition. It will be shown that the socially optimal policy is in general a combination of output and capacity based allocation. We derive conditions under which this combination is extreme, i.e. in which the optimal policy is either totally output based or capacity based. The results are obtained in a model in which demand is uncertain at the time of investment while the level of imports that will prevail will depend on the actual demand at the time of production. The interaction between these two factors is key to determine the optimal scheme. While Ellerman introduced demand uncertainty, he did not explicitly model competition between production affected and not affected by the scheme. Completing his approach allows for the precise determination of the optimal policy.

More precisely, we consider a homogeneous good produced competitively with either home or foreign plants, both productions emit pollutant emissions. Firms can invest in a fixed input, capacity, to reduce the home production cost. The home production is subject to an environmental regulation whereas imports are not regulated. Emissions from home production are taxed at the Pigouvian level but not the emissions from imports. The emissions leakage associated with this asymmetry of regulation creates a positive externality, an increase in the home production having a positive environmental effect via the reduction of imports. This positive externality calls for a subsidy on home production additional to the tax on emissions. This subsidy is similar to an output based rule of free allocation. Without uncertainty the use of such a subsidy would be the optimal regulation (given that imports are unregulated). However, the precise value of this subsidy is related to the output demand and if this demand is random or variable but the subsidy fixed, the use of a complementary policy could be justified. With demand variability the regulator would like to set an output subsidy conditional on the demand level; if he cannot do so, a subsidy on capacity could be justified for it helps to discriminate among demand states. It is particularly true if the

capacity has a stronger influence on home production when demand is large and leakage occurs. The optimal mix of both subsidies is first described in a general framework and then detailed in a simplified case, to allow for the analysis of the role of demand uncertainty, capacity constraint and the imports supply curve.

We apply our model to the case of the cement industry in Europe. The actual capacity scheme is modeled as well as the optimal scheme. With our calibration, if a border adjustment is unavailable then the optimal scheme is an output based scheme, mostly because of the low level of demand uncertainty relative to the high level of existing capacities. An important feature of this optimal scheme is the low level of the industry benchmark compared to the existing European benchmark. We demonstrate that the optimal benchmark should be based on historical emissions and on the international competitive pressure which notoriously depends, in the case of cement, on the level of the domestic demand. This second factor is ordinarily neglected, such as in the design of output based schemes in Australia (the clinker benchmark is set at 94.5% of the historical rate, reduced by 1.3% per annum). Again, but through a quite different route than for grand fathering, we find that empirical rates of allocation, this time for output based, are being set at a too high level.

Section 2 introduces the model. The optimal regulation is determined in Section 3 where a simplified case is also developed to allow for further analysis. The EU-ETS scheme for 2013-2020 to be implemented for the cement sector is compared to our optimal scheme in section 4. Section 5 concludes. Proofs are in the appendix.

2 The model

Let us consider a homogeneous good, demand of which is random. The inverse demand function is: $p(q, \theta)$. The corresponding consumer gross surplus is $S(q, \theta)$ with $\partial S / \partial q = p(q, \theta)$, where q is the total quantity consumed and θ is a random parameter, with $E\theta = 0$, distributed over $[\underline{\theta}, \bar{\theta}]$ according to the cumulative distribution F a continuously differentiable function. θ can represent either risk or time variability of the demand. We assume that p is decreasing with respect to q and increasing with respect to θ .

There are two technologies to produce this good: a home one and a foreign one. The home production is denoted q_h and the foreign production q_f , so $q = q_h + q_f$. The foreign production cost is denoted $C_f(q_f)$ a positive, strictly increasing and convex function. The home production cost is composed of two components a variable cost and a sunk cost for a capacity k . The variable cost is $C_h(q_h, k)$ in which k represents new capacity, the unit cost of a capacity is constant and equal to c_k . The investment in new capacity $c_k k$ is sunk, that is, k is chosen before the demand parameter θ is known and cannot be modified. We consider that $C_h(q_h, k)$ is increasing and convex with respect to q ; it is decreasing and convex with respect to k , and the marginal production cost is decreasing with respect to k (the cross derivative is negative).

Home and foreign productions generate polluting emissions at respective constant rates u_h and u_f , the environmental damage is assumed linear with a marginal damage σ . Environmental damage calls for a regulation of emissions. We assume that home emissions are priced

at σ , the marginal environmental damage, but that foreign emissions or production cannot be regulated. There is *leakage*, a decrease in home production decreases direct pollution but has the adverse effect of increasing foreign production and thus creating indirect emissions. This leakage calls for an additional regulation.

The regulator can subsidize home production and home capacity. The subsidy on home production is denoted s_h and the subsidy on capacity s_k . We consider a representative price-taking firm. The timing is the following:

- the regulator sets s_h and s_k ;
- the firm chooses its capacity k ;
- θ is known and the firm decides how much to produce q_h and to import q_f .

Several comments should be made on our setting. First, by considering a representative firm, we implicitly assume that the foreign plants are owned by home producers. This assumption is made mainly for a methodological reason. It allows us to focus on the environmental incentive to regulate production and to ignore the “protectionism” incentive to subsidize home production to reduce the price of imports. Second, the environmental damage is assumed linear, a change of emissions from home or foreign production does not influence the marginal environmental damage. This is relevant if the emissions from the sector under consideration are small compared to total emissions, which is the case for the sectors covered by the current ETS and exposed to international competition like the cement industry that is used for the numerical investigation of the EU-ETS. Furthermore it is coherent with the partial equilibrium approach used. Third, an ETS is not explicitly modeled, we consider a mix of price instruments (tax and subsidies) and not tradable quotas. To link the present framework to an ETS, the price σ should be interpreted as the price of emissions permits and the rates of free allowances per production unit and per capacity are respectively s_h/σ and s_k/σ . This interpretation implicitly assumes that the emissions cap is set to align the price of permits with the environmental damage in order to mimic the Pigouvian tax.

3 Optimal regulation

3.1 General Case

Let us first describe the market equilibrium. The firm’s profit is a function of the market price:

$$\pi(p, q_h, q_f, k) = pq - C_h(q_h, k) - (\sigma u_h - s_h)q_h - C_f(q_f) - (c_k - s_k)k, \quad (1)$$

from the firm perspective the price p is random, the firm chooses k with a prior distribution of market prices, then, for each price realization it chooses the home and foreign production that maximizes its profit (1). We use \mathbb{E} for the expectation operator, the firm’s long-term profit is:

$$\Pi(k) = \mathbb{E} \left[\max_{q_h, q_f} \pi(p, q_h, q_f, k) \right]. \quad (2)$$

We assume that the firm is price-taker and has rational expectations, its prior distribution of prices corresponds to the long-term equilibrium distribution $p(q_h + q_f, \theta)$.

In the short-term, k is fixed and the firm maximizes its profit (1) considering the price fixed. The price clears the market and the equilibrium productions satisfy the two first order conditions

$$p(q_h + q_f, \theta) = \sigma u_h - s_h + \partial C_h(q_h, k)/\partial q_h \quad (3)$$

$$p(q_h + q_f, \theta) = \partial C_f(q_f)/\partial q_f \quad (4)$$

if both quantities q_h and q_f are strictly positive. The home and foreign equilibrium productions are functions of the demand state θ , the production subsidy s_h and the capacity k , they are $q_h(s_h, k, \theta)$ and $q_f(s_h, k, \theta)$. It will prove useful to consider foreign production as a function of home production and the demand state. Therefore, we denote $\psi_f(q_h, \theta)$ the solution of

$$p(q_h + \psi_f, \theta) = \partial C_f(\psi_f)/\partial q_f. \quad (5)$$

At the short-term equilibrium $q_f(s_h, k, \theta) = \psi_f(q_h, \theta)$, this notation emphasizes that the subsidy on home production influences only indirectly foreign production via its direct effect on home production.

In the long-run, the firm chooses its home capacity by maximizing its long-term profit (2) and anticipating the equilibrium stream of prices. If the equilibrium capacity $k(s_h, s_k)$ is strictly positive it satisfies:

$$\mathbb{E}[-\partial C_h(q, k)/\partial k] = c_k - s_k. \quad (6)$$

The marginal cost of a capacity is equalized with the expected short-term marginal benefit from a cost reduction. The capacity is null if

$$\mathbb{E}[-\partial C_h(q, 0)/\partial k] < c_k - s_k. \quad (7)$$

Let us introduce the welfare in a state θ and the expected welfare that is the objective function to be maximized. In a state θ , the welfare is the difference between gross consumer surplus and production cost and environmental damage:

$$w(q_h, q_f, k, \theta) = S(q, \theta) - [C_h(q_h, k) + C_f(q_f) + c_k k] - \sigma [u_h q_h + u_f q_f]; \quad (8)$$

and, the expected welfare is

$$W(s_h, k) = \mathbb{E}_\theta [w(q_h(s_h, k, \theta), q_f(s_h, k, \theta), k, \theta)]. \quad (9)$$

Welfare is written as a function of s_h and k and not of s_h and s_k to disentangle the direct effect of s_h on home production from its indirect effect via the capacity. Similarly, the subsidy on capacity s_k has an effect on production via the capacity. It is actually equivalent to consider that the regulator chooses a couple of subsidies or to consider that the regulator chooses capacity directly and a subsidy on production. This equivalence is straightforward to establish with the expression (9). The standard result holds.

Lemma 1 *Welfare is maximized by taxing home and foreign emissions by σ .*

Proof. From the expression of welfare (8), a tax σ on home and foreign emissions would ensure that the first order conditions of (price-taking) firms' profit maximization coincide with the first order conditions of welfare maximization, for any given k in all states θ . Therefore, for any k the productions would be optimal. And the k chosen by firms would satisfies (6) with $s_k = 0$, which would also be satisfied by the optimal k , and by uniqueness the two would be equal.

■

If foreign emissions or production cannot be directly regulated the environmental cost $\sigma u_f q_f$ is not internalized by producers. In such a case, there is a positive externality from home *production* that comes from the reduction of foreign emissions, it partially offsets the negative externality due to domestic *emissions*.

Proposition 1 *The optimal couple of subsidies s_h, s_k satisfies:*

$$s_h = -\sigma u_f \frac{\mathbb{E}\left[\frac{\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial s_h}\right]}{\mathbb{E}\left[\frac{\partial q_h}{\partial s_h}\right]} \quad (10)$$

$$s_k = -\sigma u_f \mathbb{E}\left[-\frac{\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial k}\right] - s_h \mathbb{E}\left[\frac{\partial q_h}{\partial k}\right]. \quad (11)$$

The regulator has to set a positive production subsidy to limit leakage. The sign of the capacity subsidy is ambiguous and depends on the comparison of two terms. Before further analyzing these two instruments and the role played by uncertainty, it is worth considering the benchmark situation without uncertainty.

Corollary 1 *Without uncertainty, the production subsidy satisfies*

$$s_h = -\sigma u_f \frac{\partial \psi_f}{\partial q_h} \quad (12)$$

and the capacity subsidy is null.

Proof. From the equations of Proposition 1, without uncertainty, equation (10) gives (12); and plugging this equation into (11) gives $s_k = 0$.

■

Without uncertainty there is no need to subsidize capacity, the subsidy of production is sufficient. The right-hand side of (12) is the marginal benefit from an increase in home production. This marginal benefit is the product of three factors: the marginal cost of emissions σ , the foreign emissions rates u_f and the sensitivity of foreign production to home production $\partial \psi_f / \partial q_h$. With this subsidy the positive externality from home production is internalized by the firm and there is no need to further subsidize capacity.

With uncertainty the situation is different. The sensitivity of foreign production to home production depends upon the demand state. Consequently, the regulator would like to set

a subsidy on production *conditional* on the demand state θ . If the regulator could set a subsidy $s_h(\theta)$ in each demand state similar to (12), there would be no need to subsidize capacity. From (12), such a conditional subsidy should be larger the more sensitive imports are to home production.

From Proposition 1, the constant optimal subsidy on production is a weighted expectation of the sensitivity of imports to home production, the weights are the effect of the subsidy on the home production. The subsidy is not equal to the expected sensitivity of imports, it is either larger or lower depending on the covariance of this sensitivity and the effect of the subsidy on home production. From (10), using the fact that the expectation of a product is equal to the product of expectations plus the covariance,

$$\frac{s_h}{\sigma u_f} = -\mathbb{E}\left[\frac{\partial\psi_f}{\partial q_h}\right] + \text{cov}\left(-\frac{\partial\psi_f}{\partial q_h}, \frac{\partial q_h}{\partial s_h}\right) / \mathbb{E}\left[\frac{\partial q_h}{\partial s_h}\right]. \quad (13)$$

For instance, if both the sensitivity of imports to home production and the effect of the subsidy on the home production are increasing function of the demand state the subsidy on production is larger than the expected sensitivity of imports. Conversely, if these two coefficients are negatively correlated then the subsidy is lower than the expected sensitivity of imports.

The rationale for a subsidy on capacity comes from the inability of the regulator to discriminate among demand states when setting the production subsidy. The role played by uncertainty and the variability of the effects of the subsidy and of capacity is illustrated by the following Proposition.

Proposition 2 *If the three following conditions hold:*

- (i) *the sensitivity of imports to home production, $-\frac{\partial\psi_f}{\partial q_h}$, is increasing w.r.t. θ ,*
 - (ii) *the effect of the subsidy on the home production, $\frac{\partial q_h}{\partial s_h}$, is decreasing w.r.t. θ and,*
 - (iii) *the effect of the capacity on the home production, $\frac{\partial q_h}{\partial k}$, is increasing w.r.t. to θ ,*
- then,

$$s_k > 0 \text{ and } s_h < \sigma u_f \mathbb{E}[-\partial\psi_f/\partial q_h]. \quad (14)$$

Proof. Let us assume that (i), (ii) and (iii) are satisfied. We first rewrite the expression of the optimal subsidy on capacity.

First, the expectation of the product is the sum of the product of expectation and the covariance:

$$\mathbb{E}\left[-\frac{\partial\psi_f}{\partial q_h} \frac{\partial q_h}{\partial k}\right] = \mathbb{E}\left[-\frac{\partial\psi_f}{\partial q_h}\right] \times \mathbb{E}\left[\frac{\partial q_h}{\partial k}\right] + \text{cov}\left(-\frac{\partial\psi_f}{\partial q_h}, \frac{\partial q_h}{\partial k}\right); \quad (15)$$

then, injecting this equation and 14 into 11 the optimal subsidy on capacity satisfies:

$$\frac{s_k}{\sigma u_f} = \text{cov}\left(-\frac{\partial\psi_f}{\partial q_h}, \frac{\partial q_h}{\partial k}\right) - \text{cov}\left(-\frac{\partial\psi_f}{\partial q_h}, \frac{\partial q_h}{\partial s_h}\right) \frac{\mathbb{E}[\partial q_h/\partial k]}{\mathbb{E}[\partial q_h/\partial s_h]} \quad (16)$$

From the assumptions (i) and (ii) $\text{cov}(-\partial\psi_f/\partial q_h, \partial q_h/\partial s_h)$ is negative and from assumptions (i) and (iii) $\text{cov}(-\partial\psi_f/\partial q_h, \partial q_h/\partial k)$ is positive. Therefore, the difference between the later and the former is positive, so is s_k .

The second result comes from (14) because the second term, the covariance, is negative.

■

In the situation described in Proposition 2, the subsidy on home production has a lower influence on home production in demand states in which imports are less sensitive to a change of home production. Conversely, the capacity has a larger influence on the home production when imports are sensitive to this home production. In that case a small subsidy should be set on production because it is relatively inefficient and a positive subsidy should be set on capacity. The production subsidy is inefficient because it increases production even in demand states where leakage is not an important issue. The subsidy on capacity is justified because it ensures that the home production is large in the demand states in which there are imports. The subsidy on capacity is a way to discriminate among demand states.

3.2 A simplified specification

To illustrate the above analysis and get some further insights a quadratic version of the model is considered.

The demand is assumed linear with an additive uncertainty, $p(q, \theta) = a + \theta - bq$. Home production can be performed with new and old plants. The old plants have various variable costs depending on their age, the older plants being more expensive than the more recent ones. The cost of these old plants is $c_h q_o + 0.5\gamma_h q_o^2$ in which q_o denotes the production from old plants. The new plants have to be built. The cost of a new capacity is c_k and the variable cost of the new capacity is c_h . With these assumptions, the variable cost of home production is:

$$C_h(q, k) = \begin{cases} c_h q & \text{if } q < k \\ c_h q + 0.5\gamma_h (q - k)^2 & \text{otherwise} \end{cases} \quad (17)$$

New and old plants have identical emissions rates u_h , this emission rate could possibly be the result of an optimization procedure if c_h is a function of the emission rate u_h . If $c_h(u_h)$ is a decreasing function (a more pollutant production process is less costly) then the emissions rate u_h is the solution of $\sigma = -c'_h(u_h)$. In that case the emissions rate is determined by the price of emissions and is not influenced by the subsidies. This possibility to reduce emissions is considered in the numerical application. Concerning the foreign production, we also consider a quadratic form, i.e.,

$$C_f(q_f) = c_f q_f + 0.5\gamma_f q_f^2. \quad (18)$$

It is further assumed that in the situations considered, the price of emissions and the subsidy on production satisfy:

$$c_f > c_h + \sigma u_h - s_h. \quad (19)$$

the variable cost of home production with a new capacity is lower than the marginal cost of the first unit imported.

In that particular setting, there are three regimes in the short term, once the firm has invested in new capacities. Either the firm produces less than its new capacity, or it produces more and does not import, or it imports. There are two threshold states θ^- and θ^+ such that:

- if $\theta < \theta^-$ then $q_h < k$ and $p = c_h$;
- if $\theta^- \leq \theta \leq \theta^+$ then $q_h > k$ and $q_f = 0$;
- if $\theta^+ < \theta$ then $q_h > k$ and $q_f > 0$.

The short term equilibrium in the three regimes is depicted in Figure (1).

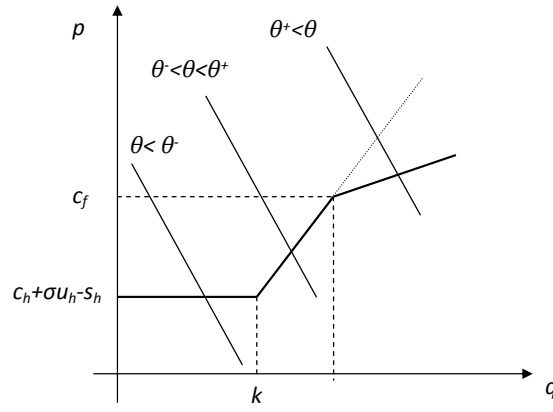


Figure 1: Short-term equilibrium for three demand states.

In the short term, with the quadratic cost (19), from the first order condition (3), the price is $c_h + \sigma u_h - s_h$ for $\theta < \theta^-$, and, it is $(c_h + \sigma u_h - s_h) + \gamma_h(q_h - k)$ for $\theta > \theta^-$. In the long term the firm chooses its capacity according to (6), with the quadratic cost it gives:

$$\int_{\underline{\theta}}^{\theta^-} 0 dF(\theta) + \int_{\theta^-}^{\bar{\theta}} \gamma_h(q_h - k) dF(\theta) = \mathbb{E}[p + s_h - c_h - \sigma u_h] = c_k - s_k. \quad (20)$$

If the firm invests in new capacity the expected price is equal to the marginal long-term cost: $\mathbb{E}[p] = c_h + c_k - (s_h + s_k) + \sigma u_h$. If the firm does not invest the expected price is lower than this long-term cost. The optimal subsidies satisfy the equations (10) and (11) in Proposition 1. With the specification it is possible to explicit the effect of the subsidy on production, the sensitivity of imports to home production and the effect of capacity on home production in the three regimes. Imports only occur in large demand states whereas both subsidies have effect in other demand states. The production subsidy has effect in all demand states whereas the capacity subsidy has an effect only in demand state where all the new capacity is used. (cf Appendix)

Corollary 2 *With the linear specification, the optimal couple of subsidies satisfies:*

$$s_h = \sigma u_f \frac{b}{b + \gamma_f} \frac{1 - F(\theta^+)}{1 - F(\theta^+) + A} \quad (21)$$

$$s_k = s_h \frac{\gamma_h}{b} F(\theta^-), \quad (22)$$

in which

$$A = \left[\gamma_h + \gamma_f \frac{b}{b + \gamma_f} \right] \left[\frac{F(\theta^-)}{b} + \frac{F(\theta^+) - F(\theta^-)}{b + \gamma_h} \right]. \quad (23)$$

In this specification the conditions of Proposition 2 are not fully satisfied. Conditions (i) and (iii) on the respective variations of the effect of home production on imports and of the capacity on home production are satisfied, but condition (ii) is not. The effect of the subsidy on home production first decreases with θ : it is higher when there is excess capacity ($\theta < \theta^-$) than when capacity is fully used without imports ($\theta^- < \theta < \theta^+$); then it increases for $\theta^+ < \theta$ because it is amplified by the adjustment of imports. However, the interpretation is similar. The production subsidy and the capacity have different effects on the home production according to the demand state, and these variations are not synchronized. Most importantly, the capacity does not influence home production in low demand states in which it is not fully used (the states $\theta < \theta^-$) whereas the production subsidy does. There is no import in those states; they correspond to states in which the regulator would set a null subsidy if it were possible. The production subsidy is distortive in these states whereas the capacity subsidy is not. The presence of these states therefore justifies to limit the production subsidy and subsidize capacity.

Corollary 3 *The optimal subsidy on capacity is positive iff, at the optimal capacity, there are demand states in which the home production is lower than the new capacity (i.e. $F(\theta^-) > 0$); it is null otherwise.*

The expression (21) is worth some attention. The rate of free allocation per production unit (for the output based component of the scheme) is

$$u_f \frac{b}{b + \gamma_f} \frac{1 - F(\theta^+)}{1 - F(\theta^+) + A}.$$

The first factor is the rate of foreign emissions, the second one is the sensitivity of imports to home production when imports occurs, and the third factor is the ratio between the expected effect of the subsidy on production in large demand states (in which imports occur) and the expected effect of the subsidy on production in all demand states. The latter ratio can be interpreted as a measure of the efficiency of the subsidy, the subsidy is relatively efficient if it increases production mainly in states in which imports occur. In that case the ratio would be close to unity. On the contrary, the subsidy is inefficient if it has a large impact

on production in states in which there is no import, a situation in which the ratio would be small. If imports occur in all demand states then $A = 0$ ($F(\theta^+) = 1$ and $F(\theta^-) = 0$) and the production subsidy is $\sigma u_f b / (b + \gamma_f)$ which corresponds to the subsidy without uncertainty; otherwise, the subsidy should be lower.

It is worth stressing that if the emissions rates of imports and of home production are close, the optimal rate of free allocation should be lower than u_h , which corresponds to a full recycling of permits (for the sector considered). It would be lower for two reasons: because the sensitivity of imports to home production is lower than unity ($\gamma_f > 0$), and because imports might not occur in all demand states ($A > 0$).

3.3 The case of no old plants

An extreme version of the quadratic model that is worth considering is the case where $\gamma_h = +\infty$, in that case there are no old plants. The firm can only use its new capacity to produce. This specification can also describe a situation where there is a fixed amount k_o of old plants with the same variable cost as new plants and the firm decides to build $k - k_o$ new plants; k would be the quantity of plants, old and new, available to the firm in the short term. In that case there is a strong capacity constraint for home production that is not binding in low demand states and binding for high ones.

Corollary 4 *If there are no old plants, i.e. $\gamma_h = +\infty$, two situations can arise:*

- *if there are demand states in which the capacity constraint is not binding, $F(\theta^-) > 0$, the production subsidy is null and the capacity subsidy is positive;*
- *else, if the home capacity is fully used in all demand states the two instruments are equivalent and only the sum $s_h + s_k$ matters.*

In that specification of the model the subsidy on capacity is more efficient than the subsidy on production because imports are influenced by the capacity and not by the variable cost. To subsidize production has the drawback of increasing production even in states in which imports do not occur whereas the capacity subsidy is more efficient because it does not influence production in low demand states.

4 A numerical application to the European cement market

In this section, the model is applied to the EU cement sector.¹ We chose this sector because it features one of the highest CO₂/value added ratios (Hourcade et al., 2007) and had the highest emissions of all the manufacturing industry sectors covered by the EU-ETS in phase

¹More precisely, to the EU grey clinker market excluding white cement, which refers to a different production process and a different market.

1 (2005-2007; cf. Kettner et al., 2008). In order to stay as close as possible from the analytical model presented above, we abstract from some features of the cement market, such as imperfect competition within the EU, exports, geographic differentiation. We shall come back to the possible role of these features in the concluding section.

4.1 Calibration of a No Policy scenario

A No Policy scenario is used as a counterfactual. This scenario refers to a representative year of the period 2013/2020.² The demand for that year may be high or low, with equal probability. Prior to that period the EU cement industry invests some new capacity. Once the demand is known, domestic production (from new and old plants) and imports meet the demand.

This scenario is calibrated using data from 2007 as a high demand year and 2009 as a low demand year (see table 1 part 1). Since the EU-ETS 2013-2020 concerns clinker and not cement our numerical values are for clinker using the clinker/cement ratio of 78%, coming from the WBCSD CSI GNR database.³

More precisely, we use clinker production from the cement production data provided by the European cement manufacturer association activity reports (Cembureau 2007, 2009). There is no publicly available clinker price data (and no publicly available cement price data). We compute a clinker unit value from the UN Comtrade database⁴ by dividing the value of EU imports by their volume. This database also provides the volume of imports. As expected, for the peak year 2007 imports are higher relative to domestic production than for the recession year 2009, 11% versus 6 %.

The slope of the demand curve is set at 2, which brings a price elasticity of demand between -0.5 and -1.1, i.e. in the range of published estimates, whatever the state of demand and the policy scenario.⁵

The production from new plants is estimated indirectly. Firstly, there is no published estimate of new clinker capacities since Cembureau stopped publishing plant-level data in 2002.⁶ Secondly, the amount of “new” clinker production capacity obviously depends on the length of the period considered. Hence, the figure retained (20 Mt of yearly production capacity during the period considered) should be taken as illustrative. However, it corresponds

²An alternative interpretation is to consider that we simulate the adoption of EU-ETS 2013-2020 scheme in year 2005, and compare it with several other schemes. The No-Policy scenario then corresponds to what actually happened through 2005 to 2009, under the assumption that the industry had anticipated an uncertain demand corresponding to the high and low demands of the years 2007 and 2009.

³<http://www.wbcscement.org/>

⁴<http://comtrade.un.org/db/>

⁵Röller and Steen (2006) estimate a short-run elasticity of -0.46 and a long-run elasticity of -1.47, based on Norwegian data.

⁶Admittedly, the US Geological survey (2011) publishes end-year clinker capacities for France, Germany, Italy and Spain, but they cannot be directly used for two reasons. Firstly, we have some doubts on their accuracy because they do not match Cembureau capacity data which were published until 2002. Secondly, the US Geological survey publishes only end-year capacity, which is increased by plant creation but reduced by plant closure, with no possibility to disentangle these two effects.

roughly to the amount of capacity added in the EU 27 in the last ten years during which Cembureau plant-level data were available, assuming that a clinker kiln has an average yearly capacity of 1 Mt.

With these data, we run the model backwards with a zero CO₂ price,⁷ in order to find the parameters that are consistent with the above-mentioned data. We proceed in three steps. Step 1, c_h and $1/\gamma_h$ are obtained through supply and demand equations in both demand states. Step 2, we proceed similarly to get c_f and $1/\gamma_f$ introducing imports in these equations. Step 3, c_k is obtained using an expected zero profit condition for investment in new capacity. The marginal cost of imports increases from 60 €/t to 80 €/t when imports are 10 Mt and 30 Mt corresponding respectively to the high and low demand states. Investment in new plants generates a total marginal cost of 70€/t (45+25) which corresponds to the average clinker price. Producing 100 Mt through old plants would generate a marginal cost of 50€/t (25+100/4) and with 200Mt it would be 75€/t.

The values of these calibrated parameters are given in Table 1 part 2. Note that annualized fixed cost may seem high in comparison to some estimates in the grey literature (e.g. BCG, 2008, or Exane BNP Paribas, 2006) but they implicitly include labor costs,⁸ a profit margin and all the administrative costs incurred by the authorization procedure to operate a new clinker plant in Europe.

The parameters given in Table 1 part 3 do not concern the No Policy scenario but the scenarios to be studied. They are linked to emissions and abatement. Firstly, all EU plants are assumed to have the same specific emissions,⁹ and the same stands for all foreign plants, but specific emissions of EU and foreign plants differ. Secondly, the marginal abatement cost curve is assumed to be linear: every extra €/t CO₂ brings the same extra abatement per tonne of clinker. Thirdly, the abatement cost is assumed to be part of the variable cost, not of the investment cost, which allows a symmetric treatment of new and existing plants and is a common assumption in the literature. Average specific emissions in the EU are taken from the cement sector report which served as a basis to set the benchmark for free allocation in phase III of the EU-ETS (Ecofys et al., 2009). Average specific emissions in the rest of the world are taken from the WBCSD CSI database, and slightly corrected to be more consistent with our figure for EU emissions. The CO₂ price is 20 €/t. CO₂, in line with forecasts for 2020 if the EU GHG target remains at -20% compared to 1990 (Grubb and Cooper, 2011) and the parameter of the MAC curve is such that this price reduces specific emissions by ca. 10%.

⁷We abstract from the possible impact from the EU-ETS during those years, given the high level of free allowances and industry behavior based on average rather than marginal carbon price (Ellerman et al. 2010)

⁸In this context, labor costs cannot be considered as variable costs since specific qualifications are required to operate a clinker plant. Hence firms cannot simply fire workers when demand is low and hire them again when demand recovers.

⁹Admittedly, some plants emit more than others, with specific emissions in the EU ranging from ca. 750 to ca. 1150 kg CO₂/t (Ecofys et al., 2009). However, accounting for this heterogeneity in our model would have required heroic assumptions about the correlation between specific emissions and production cost, since no such information is publicly available to our knowledge.

Part 1: Data used for calibration of the No Policy scenario		
Variable	Value	Source
Demand curve slope (1/b)	2 Mt/(€/t)	Own estimation
Clinker price (high demand - h.d.)	80 €/t	UN Comtrade (2007)
Clinker price (low demand - l.d.)	60 €/t	UN Comtrade (2009)
Production from existing plants (h.d.)	220 Mt/yr	Cembureau (2007)
Production from existing plants (l.d.)	140 Mt/yr	Cembureau (2009)
Production from new plants	20 Mt/yr	Own estimation
Imports (h.d.)	30 Mt/yr.	UN Comtrade (2007)
Imports (l.d.)	10 Mt/yr.	UN Comtrade (2009)

Part 2: Parameters calibrated	
Parameter	Value
Expected demand curve intercept	360 Mt/yr
Standard deviation of θ	70 Mt/yr
Annualized fixed cost of capacity (c_k)	45 €/t
Operational cost of new plants and of the least costly existing plant (c_h)	25 €/t
price of cheapest import (c_f)	50 €/t
Slope of existing plants supply curve ($1/\gamma_h$)	4Mt/(€/t)
Slope of imports supply curve ($1/\gamma_f$)	1Mt/(€/t)

Part 3: Additional parameters used for the other scenarios		
Parameter	Value	Source
CO ₂ price (σ)	20 €/t	Grubb and Cooper (2011)
Benchmark for free allocation in the ETS	766kg CO ₂ /t	E.C. (2010)
Specific emissions, EU27 (u_h for $\sigma = 0$)	858 kg CO ₂ /t	E.C. (2010)
Specific emissions, rest of the world (u_f)	852 kg CO ₂ /t	WBCSD + E. C. (2010)
MAC curve slope	0.2 €/ kg CO ₂ [†]	Own estimation

[†] For $\sigma = 20\text{€/t}$, the emission rate is $u_h = 758 \text{ kg CO}_2/\text{t}$

Table 1: Calibration of the No-Policy scenario and additional parameters

4.2 The allocation mechanism in EU-ETS for 2013-2020 the cement sector¹⁰

In December 2008, major changes to the EU-ETS were decided, which will be applied from 2013 onwards (phase III of the EU-ETS). In particular, a majority of allowances will be auctioned. However, sectors deemed at risk of carbon leakage (including clinker manufacturing) will continue to receive free allowances. Every year, the operator of installations in these sectors will receive a number of allowances equal to a benchmark times an activity level. The clinker benchmark equals 766 kg CO₂/t. clinker; it was calculated as the average specific emissions of the 10% most CO₂-efficient clinker kilns in the EU. Using Table 1, old plants will receive a credit allowances of 15€(20 €/tCO₂ × 0.760 tCO₂/tclinker) per unit of 2007 production.

For existing installations, the activity level is the installation’s historic production expressed as the median of the years 2005-08 or 2009-10, whichever is higher. In order to ensure that free allowances are not allocated to installations which have subsequently ceased operation, the Directive states that no allowance will be allocated to installations that have stopped operating. In the event that an installation has only partially ceased operations, specific thresholds determine the number of emission allowances that should be allocated to such an installation. However, if the activity level of an installation does not drop below 50% of the initial activity level, the installation will still receive 100% of its allocation. Thus, it is unlikely that this “closure rule” will have a significant impact, because operators have an incentive to reduce production homogeneously in their plants in order not to reach the 50% threshold. When modeling this policy we assume that the closure rule is strategically ineffective, so free allocation to existing firms is, economically, a lump-sum transfer that does not interfere with the investment decision.

For new installations (which includes capacity extensions in existing plants), the free allowances are provided from the New Entrants Reserve. Given the lack of historical production data for new installations, the preliminary allocation of allowances is calculated by multiplying the benchmark by the installation’s capacity (or capacity increase) and a standard capacity utilization factor. Using Table 1, it amounts to subsidizing investment by 15 €/t which is one third of the investment cost (45€/t).

To sum up, we will model allowance allocation in the EU-ETS as a lump-sum transfer for existing plants plus free allowances for new installations, proportional to the installation’s capacity.

4.3 Scenarios

For completeness we shall consider six scenarios:

1. **No-Policy**: no climate policy as calibrated in section 4.1.
2. **Auction**: full auctioning, no recycling of auction revenues. In other words, auction revenues are used to reduce public deficits.

¹⁰This section is largely based on Quirion et al. (2012).

3. **NER**: New Entrant Reserve, i.e. free allocation for new plants, no free allowances (i.e. auctioning) for the other plants. Every new plant receives the same number of allowances per unit of production capacity.
4. **EU-ETS**: new entrants reserve as in NER plus a lump-sum allowance transfer for existing plants (cf. section 4.2). The lump-sum transfer is based on the EU-ETS benchmark (0.766 tonne CO₂/tonne clinker) times the production of year 2007 (Table 1) minus the capacity of the new plants associated with this scenario (assumed to substitute inefficient old plants).
5. **OBA** (Output-Based Allocation): for every tonne of grey clinker produced in the EU, firms receive a given number of allowances. The standard academic approach to OBA is to use as a benchmark the actual emission rate of home plants after abatement (i.e. 0.758 tonne CO₂/tonne clinker, cf. Table 1). This scenario is denoted OBA⁰. As we shall prove later on it turns out that our optimal policy (assuming out border adjustment) would be an OBA policy but with a different benchmark (0.284 tonne CO₂/tonne clinker). This scenario is denoted OBA*.
6. **BTA** (border adjustment with full auctioning, no revenue recycling): To be allowed to import into the EU, firms have to pay the CO₂ price times an adjustment factor. The optimal BTA policy is based on a benchmark corresponding to the emission rate of foreign plants, assumed to be identical and equal to 0.852 tonne CO₂/tonne clinker (cf. Table 1). This scenario is denoted BTA*.

4.4 Results

The theoretical analysis helps us to understand the relative merit of the various scenarios. The first best policy is BTA* (cf Lemma 1). Assuming that BTA policies are excluded the optimal second best policy is to use a combination of capacity and output based allocations (Corollary 2). Based on the calibrated No Policy scenario it turns out that only output based allocations are required (Corollary 3 applies). This result can be stated as follows, which shows that OBA* is indeed the optimal policy.

Corollary 5 *With the linear specification corresponding to the No Policy scenario, the optimal couple of subsidies satisfies:*

$$s_h/\sigma = u_f \frac{b}{b + \gamma_f} = .284t \text{ CO}_2/t \text{ clinker} \quad (24)$$

$$s_k = 0. \quad (25)$$

With this policy the credit allowance is only at 5.7€/t clinker (versus 15.3€/t with the EU-ETS).

Uncertainty does not play a significant role with our specification. The optimal output based rate is not influenced by uncertainty, because there are imports in both demand states.

Furthermore, given the linearity of our framework the expected quantities correspond to the quantities with a constant demand. With a larger uncertainty, the situation would be different. If the uncertainty were sufficiently large so that imports would occur only in the high demand state but new capacities would still be fully used in both demand states ($F(\theta^+) = 0.5$ and $F(\theta^-) = 0$) the optimal subsidy would be lower (3.2 €/t clinker), in order to limit the distortion in the low demand state. For a larger uncertainty imports would occur only in the high demand state and capacity would be in excess in the low demand state ($F(\theta^+) = 0.5$ and $F(\theta^-) = 0.5$); in such a case, the output subsidy would be even lower (2.6 €/t clinker) and a capacity subsidy would be justified (0.7 €/t clinker). Such a situation is possible for a country that faces a relatively high import price and a rapidly increasing demand (with few old plants relatively to the market size). China, which is currently implementing several permits market at the regional level, would correspond to these characteristics.

The optimal output based rate is low because so is the sensitivity of imports to home production ($b/(b + \gamma_f) = 1/3$). In our specification the domestic product and the imported one are perfect substitute, however, a reduction of the home production by 1 does not increase imports by 1 because of the convexity of the imports cost. With a specification *à la* Armington, in which home and foreign productions are imperfect substitutes, without uncertainty the optimal output based rate would satisfy an equation similar to (12) and the sensitivity of imports to home production would be determined by both the imports cost convexity and the substitutability between home and foreign production. Fischer and Fox (2012) use such a specification, with imperfect substitution, but they do not consider the optimal output based scheme, they consider a scheme in which all permits are freely allocated which would correspond to $s_h = \sigma u_h$. Such an OBA scheme corresponds to the way most OBA schemes are conceived. For instance, in the Australian scheme the sensitivity of imports to domestic production is not taken into consideration.

4.4.1 Investment and production

Table 2 gives the investment in new capacity and, for each demand state, production from new plants and old plants and imports. Note that the investment in new plants would jump from 20 Mt with No-Policy to 79 Mt with EU-ETS or NER, would remain almost unaffected with OBA⁰ (17 Mt) while there would be no investment with the other scenarios. The EU-ETS or NER schemes would trigger an over-investment in productive capacity in Europe (a point emphasized by Ellerman, 2008, for NER in the electricity sector).

	No-Policy	Auction	OBA		EU-ETS & NER	BTA*
			OBA*	OBA ⁰		
Investment	20	0	0	17	79	0
Low demand						
New plants	20	0	0	17	79	0
Old plants	140	124	133	140	79	133
Imports	10	22	19	11	11	7
Total	170	146	152	168	168	141
High demand						
New plants	20	0	0	17	79	0
Old plants	220	204	213	220	159	213
Imports	30	42	39	31	31	27
Total	270	246	252	268	268	241

Table 2: Investment, production and imports in low and high demand states in Mt

4.4.2 Price of clinker, firms' profits and public revenues

For each scenario and each demand state Table 3 gives the price for clinker, the detailed profits from new and old plants and from imports. It also gives the public revenues from permits and the total amount of free allocations. By assumption the expected profit for new plants is zero (expected operating revenues exactly cover investment cost). The level of free allocations for old plants for EU-ETS is calculated as the unit carbon price (20 €/t) times the production of year 2007 (240 Mt) minus the investment in new plants (79 Mt) times the EU-ETS benchmark (0.766 tonne CO₂/tonne clinker). Observe that actual production from old plants for low demand (79 Mt) remains approximately at 50% of the capacity benchmark (161 Mt).

Relative to No Policy, on average, firms' profit increases by 4% with EU-ETS and decrease by 7% with OBA*. The price of clinker would be higher with OBA*. This is so firstly because new capacity creates a larger supply and, secondly, because existing plants still have to pay for their emissions while with OBA* the output based mechanism allows them to pass some of the carbon cost into the price. As expected there would be almost no changes with OBA⁰. BTA* would lead to significant price increase and profits decrease (due to the price signal). Qualitatively these results are in line with the literature. The important thing to note is the very substantial increase in firms' profits with EU-ETS relative to OBA* (+4% vs -7%) obtained through a decrease in public revenues of €2.3 billions (- 647 M€ versus 1.634M€).¹¹ This amount of money would presumably come from the public revenues collected from emissions from other sectors (mainly from electricity).

¹¹With a completely different methodology, Martin et al. (2012) found an overcompensation of €6.7 billions for all sectors covered by the EU-ETS.

	No-Policy	Auction	OBA		NER	EU-ETS	BTA*
			OBA*	OBA ⁰			
Low demand							
Price (€/t)	60	72	69	61	61	61	75
Profits (M€) from							
- old plants	2450	1913	2227	2450	775	3226	2227
- new plants	-200	0	0	-170	-788	-788	0
- foreign plants	50	244	178	60	59	59	28
Total profits	2300	2156	2405	2340	46	2497	2255
Public revenue	0	1876	1258	0	1183	-1252	2012
Free allocation	0	0	758	2380	1207	3642	0
High demand							
Price (€/t)	80	92	89	81	81	81	95
Profits (M€) from							
- old plants	6050	5188	5696	6050	3149	5600	5696
- new plants	200	0	0	170	788	788	0
- foreign plants	450	886	754	480	476	476	377
Total profits	6700	6073	6450	6700	4412	6863	6074
Public revenue (M€)	0	3088	2009	0	2394	-42	3222
Free allocation (M€)	0	0	1212	3335	1207	3658	0
Average							
Profits dom.(M€)	4250	3551	3961	4250	1962	4413	3961
Profit vs No Policy(%)		-16%	-7%	0%	-54%	4%	-7%
Public revenue (M€)	0	2481	1634	0	1788	-647	2617
Free allocations (M€)	0	0	985	2987	1207	3642	0

Table 3: Profits, Public revenue and Free Allocation

4.4.3 Emissions and Leakage

A standard criterion used in the literature to compare policies is the leakage-to-reduction ratio, or leakage ratio, i.e. the increase in emissions in foreign countries divided by the decrease in emissions in the EU. The results are given in Table 4. The ratio reaches 22% under Auctioning, less than the values obtained by Demailly and Quirion (2006) as well as by Ponsard and Walker (2008) but more than those obtained by Monjon and Quirion (2011a, 2011b). With BTA* the ratio is negative (i.e. foreign emissions decrease). This negative leakage rate also appears in many other simulations of border adjustments (e.g. Demailly and Quirion, 2008, Manders and Veenendaal, 2008, Mathiesen and Maestad, 2004 and Monjon and Quirion, 2011a). The explanation is that less clinker is exported into the EU than under No-Policy.

The comparison between OBA* (19%) the EU-ETS (3%) and OBA⁰ (4%) suggests that OBA* performs poorly. But this comparison would be misleading! Indeed, as reported in Table 4 the level of CO₂ emissions arising from EU consumption (including imports) is lower with OBA* (156 Mt) than with EU-ETS (167 Mt) or with OBA⁰ (again 167 Mt). This discussion suggests that the leakage to reduction ratio is a bad of the relative merits of each scenario, with respect to both their efficiency and to their environmental impact.¹² This will be confirmed by the subsequent welfare analysis.

	No-Policy	Auction	OBA		EU-ETS & NER	BTA*
			OBA*	OBA ⁰		
Emissions (Mt)						
from domestic production	172	124	131	149	150	131
from imports	17	27	25	18	18	15
Total	189	151	156	167	167	146
Leakage ratio (%)	-	22	19	4	3	-5

Table 4: Leakage to reduction ratio and Emissions averaged over each scenario.

4.4.4 Welfare

Figure 2 depicts the welfare variation compared to the No-Policy scenario, in percentage. To highlight the discussion the welfare for each class of scenario is drawn as a function of the allowance allocation or border adjustment per tonne of clinker. As expected, the welfare maximizing policy is BTA*. The the associated curve is flat on the top so with a lower

¹²The comparison of leakage ratios makes more sense if the abatement in the EU is kept constant across scenarios. In our partial analysis only emissions related to the cement industry are considered. With an emissions permits market an increase in the emissions from cement production would be offset by a reduction of the emissions in other sectors via an increase of the permit price. From a welfare perspective it would eventually call for a relaxation of the global cap in order to realign the permit price with the emission marginal cost.

adjustment set at the level of the EU benchmark, 0.766 t. CO₂/t. clinker, as proposed by Monjon and Quirion (2010), welfare would be almost as high.

Although less efficient than border adjustment, OBA brings a higher welfare than Auctioning if not too generous, the optimal allocation being for OBA*. NER & EU-ETS has the same impact as Auctioning if the allocation rate per tonne of clinker capacity installed is quite low, because no investment in new plants takes place anyway, which is also the case under Auctioning. If the allocation rate is higher than 0.204 CO₂/t. clinker, new capacity is installed and the impact on welfare is strongly negative. To sum up, welfare with OBA* would be 0.7% lower than with BTA* but 5% higher than with EU-ETS.

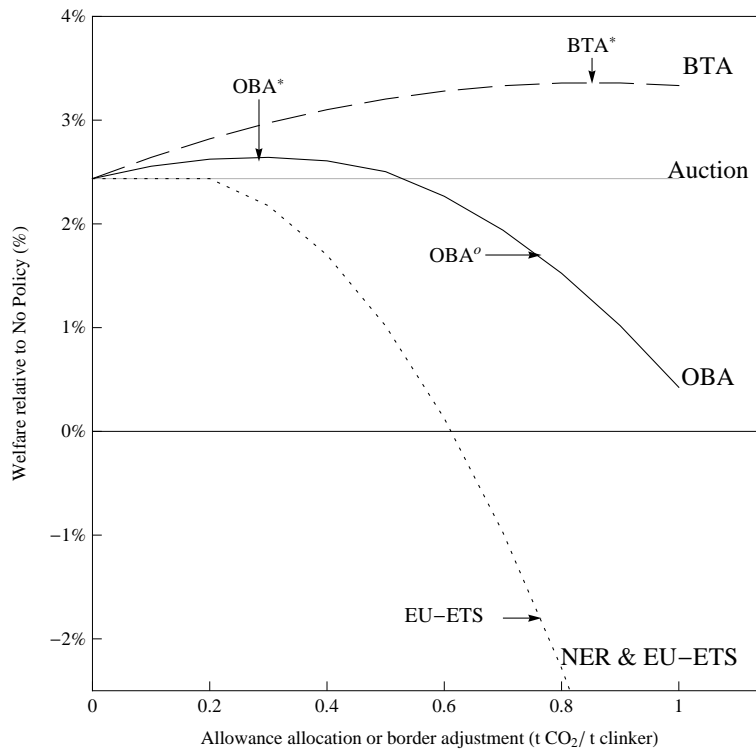


Figure 2: Welfare compared to No-Policy.

5 Conclusion

This paper provides an original setting to analyze the design of allocation schemes giving due attention to energy intensive internationally traded industries. It has been argued that, in absence of carbon trade adjustments, the fragmentation of the CO₂ prices at the world level might induce significant competitiveness and leakage issues. When border tax adjustment are excluded two schemes are usually introduced to mitigate these issues: output based and capacity based allocations. Our analysis allows for the determination of the socially optimal second best scheme: ordinarily a combination of these two schemes. The respective levels of subsidization of investment and production are also determined, and shown to be much

lower than what is usually applied in practice. Indeed we show that focusing on an indicator such as the leakage to reduction ratio would be quite misleading. It seeks to balance home and foreign emissions percentage-wise while what matters for welfare is the total emissions associated with home consumption. Using this ratio independently of welfare consideration would encourage to set a much too high benchmark in an output based allocation scheme.

Our analytical framework integrates an important feature that had been totally absent in previous economic analyzes of allocation schemes, i.e. the interaction between the international competitive pressure and demand uncertainty. To explicitly discuss the relative merits of capacity versus output based allocation, this interaction is essential. This had been known for a long time in the electricity sector (the optimal capacity mix in that case) but its implications had not been taken into consideration in comparing various allocation mechanisms in an international environment when their long term implications in terms of relocation of investments matters.

The case of the EU cement sector is discussed in view of our results. We show that the policy that is to be implemented for years 2013-2020 will induce a welfare loss of approximately 5% relative to the optimal policy, leading to an over investment in new plants of approximately 80 Mt clinker. Altogether the financial transfer to the cement sector (subsidies for new plants and grand fathering for old plants) will amount to more than €2.3 billions, assuming a CO₂ price of 20€/t CO₂. While our model does not introduce industry specificities such as the oligopolistic structure, the role of geography, or of multi plant ownership, nor a proper dynamic schedule to allow for the explicit lifetime of cement plants we believe that it remains an important argument to question the EU-ETS scheme for 2013-2020.

Our analysis has also important policy relevance for the other ETS that are or will be implemented in the near future such as in Australia, New-Zealand or in California. In such cases, an output based scheme is selected with a benchmark in line with the home rate of emissions. Our analysis suggests that a much lower benchmark would be appropriate.

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Proof of proposition 1

With the expression of expected welfare in (9) written as a function of s_h and k , the objective of the benevolent regulator is to maximize $W(s_h, k(s_h, s_k))$. The subsidies s_h and s_k are used to influence home production and capacity. The influence of the subsidy s_k on home production is only indirect via the choice of capacity. There is at least one couple of optimal subsidies, because W is continuous, bounded and the choice set of subsidies could be restricted to a compact set. The couple of optimal subsidies satisfies the couple of first order conditions:

$$\frac{\partial W}{\partial k} \frac{\partial k}{\partial s_k} = 0 \text{ and } \frac{\partial W}{\partial s_h} + \frac{\partial W}{\partial k} \frac{\partial k}{\partial s_h} = 0 \quad (26)$$

which are equivalent to the couple of equations:

$$\frac{\partial W}{\partial k} = 0 \text{ and } \frac{\partial W}{\partial s_h} = 0. \quad (27)$$

The problem is therefore similar to the choice of s_h and k to maximize $W(s_h, k)$.

The derivatives of welfare in a state θ (cf eq. 8) with respect to s_h for a given k is, using the first order conditions (3) and (4),

$$\left[\frac{\partial w}{\partial q_h} + \frac{\partial w}{\partial q_f} \frac{\partial \psi_f}{\partial q_h} \right] \frac{\partial q_h}{\partial s_h} = [-s_h - \sigma \partial \psi_f \partial q_h] \frac{\partial q_h}{\partial s_h}. \quad (28)$$

Therefore, the first order condition is :

$$\mathbb{E} \left[\left(-s_h - \sigma \frac{\partial \psi_f}{\partial q_h} \right) \frac{\partial q_h}{\partial s_h} \right] = 0 \quad (29)$$

and the expression (10) follows. Concerning the choice of s_k , from the first order conditions satisfied by productions, (3) and (4), and by the capacity (6) one gets

$$\frac{\partial W}{\partial k} = \mathbb{E} \left[\left(\frac{\partial w}{\partial q_h} + \frac{w}{\partial q_f} \frac{\psi_f}{\partial q_h} \right) \frac{\partial q_h}{\partial k} \right] - \mathbb{E} \left[\frac{\partial C_h(q_h, k)}{\partial k} \right] - c_k \quad (30)$$

$$= \mathbb{E} \left[(-s_h + \sigma u_f \frac{\psi_f}{\partial q_h}) \frac{\partial q_h}{\partial k} \right] - s_k \quad (31)$$

the expression (11) follows.

The quadratic example

Equilibrium

First, the short-term equilibrium should be described. In all demand states θ , there is a unique couple of non-negative productions q_h and q_f such that

$$q_h > 0, \text{ and } p = \partial C_h / \partial q_h$$

and, concerning foreign production, either $q_f = 0$ and $p < c_f$, or $q_f > 0$ and $p = \partial C_f / \partial q_f$. This is so because $c_f > c_h + \sigma u_h - s_h$. Three situations can occur whether the home production is smaller or larger than k , and whether the foreign production is positive or null. Given the assumption $c_f > c_h + \sigma u_h - s_h$ there is no import if $q_h < k$. Both productions are increasing with respect to θ so there are two thresholds θ^- and θ^+ such that $q_h < k$ if and only if $\theta < \theta^-$ and $q_f > 0$ if and only if $\theta > \theta^+$.

1. If $\theta < \theta^-$ then $p = c_h + \sigma u_h - s_h$ and

$$q_h = [(a + \theta) - (c_h + \sigma u_h - s_h)]/b. \quad (32)$$

2. If $\theta^- \leq \theta \leq \theta^+$, then $p = c_h + \sigma u_h - s_h + \gamma_h(q_h - k)$ so

$$q_h = [(a + \theta) - (c_h + \sigma u_h - s_h - \gamma_h k)]/[b + \gamma_h]. \quad (33)$$

3. If $\theta^+ < \theta$, then $p = c_f + \gamma_f q_f$ so

$$\psi_f = [a + \theta - b q_h - c_f]/[b + \gamma_f], \quad (34)$$

and injecting this expression into the first order condition $p = c_h + \sigma u_h - s_h + \gamma_h(q_h - k)$ gives

$$q_h = \left[(a + \theta) + \frac{b}{\gamma_f} c_f - \left(1 + \frac{b}{\gamma_f}\right) (c_h + \sigma u_h - s_h + \gamma_h k) \right] \left[b + \gamma_h \left(1 + \frac{b}{\gamma_f}\right) \right]^{-1} \quad (35)$$

The expressions of the threshold states could be found by noting that $p(k, \theta^-) = c_h + \sigma u_h - s_h$ and $p(q_h, \theta^+) = c_f$ with q_h given by the expression (33).

Proof of Corollary 2

With the expressions above we can determine the expressions of the subsidies. First,

$$-\frac{\partial \psi_f}{\partial q_h} = \begin{cases} 0 & \text{if } \theta < \theta^+ \\ b/(b + \gamma_f) & \text{otherwise} \end{cases}$$

and

$$\frac{\partial q_h}{\partial s_h} = \begin{cases} 1/b & \text{if } \theta < \theta^- \\ 1/(b + \gamma_h) & \text{if } \theta^- < \theta < \theta^+ \\ [\gamma_h + b\gamma_f/(b + \gamma_f)]^{-1} & \text{otherwise} \end{cases}.$$

With these expressions the expected effect of the subsidy on home production is

$$\mathbb{E} \left[\frac{\partial q_h}{\partial s_h} \right] = \frac{F(\theta^-)}{b} + \frac{F(\theta^+) - F(\theta^-)}{b + \gamma_h} + \frac{1 - F(\theta^+)}{\gamma_h + b\gamma_f/(b + \gamma_f)};$$

and the expected effect on home production times the effect of home production on imports is:

$$\mathbb{E} \left[\frac{-\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial s_h} \right] = \frac{b}{b + \gamma_f} \frac{1 - F(\theta^+)}{\gamma_h + b\gamma_f/(b + \gamma_f)};$$

injecting these two last equations into (10) gives (21) with the expression (23) of A .

Concerning the subsidy of capacity s_k , the effect of k on production is

$$\frac{\partial q_h}{\partial k} = \begin{cases} 0 & \text{if } \theta < \theta^- \\ \gamma_h/(b + \gamma_h) & \text{if } \theta^- < \theta < \theta^+ \\ \gamma_h [\gamma_h + b\gamma_f/(b + \gamma_f)]^{-1} & \text{otherwise} \end{cases} .$$

Therefore, we have

$$\mathbb{E} \left[\frac{\partial q_h}{\partial k} \right] = \gamma_h \left\{ \mathbb{E} \left[\frac{\partial q_h}{\partial s_h} \right] - \frac{F(\theta^-)}{b} \right\} \text{ and } \mathbb{E} \left[\frac{-\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial k} \right] = \gamma_h \mathbb{E} \left[\frac{-\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial s_h} \right]$$

so, injecting these two equalities into (11) gives

$$\begin{aligned} s_k &= \sigma u_f \mathbb{E} \left[\frac{-\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial s_h} \right] \left[\gamma_h - \frac{\mathbb{E}[\partial q_h / \partial k]}{\mathbb{E}[\partial q_h / \partial s_h]} \right] \\ &= \sigma u_f \mathbb{E} \left[\frac{-\partial \psi_f}{\partial q_h} \frac{\partial q_h}{\partial s_h} \right] \gamma_h \frac{F(\theta^-)/b}{\mathbb{E}[\partial q_h / \partial s_h]} = \gamma_h \frac{F(\theta^-)}{b} s_h \end{aligned}$$

which corresponds to the expression (22).

Proof of Corollary 3

In case of no old plants, in the short term the situation is slightly different because for $\theta > \theta^-$, the home production is exactly equal to the new capacity k . The effects on production of the subsidy and of capacity are of the subsidy on production is :

$$\frac{\partial q_h}{\partial s_h} = \begin{cases} 1/b & \text{if } \theta < \theta^- \\ 0 & \text{otherwise} \end{cases} \quad \text{and} \quad \frac{\partial q_h}{\partial k} = \begin{cases} 0 & \text{if } \theta < \theta^- \\ 1 & \text{otherwise} \end{cases} .$$

these expressions are the limits of the previous expressions for when γ_h tends to infinity. There at least one couple of subsidies that maximizes welfare. This couple satisfies the two first order conditions (10) and (11). It is straightforward to see that in that extreme case the subsidy does not influence home production when there are imports so $s_h = 0$ and, on the contrary, the capacity determines home production in states in which imports occur. From (11)

$$s_k = \sigma u_f \frac{b}{b + \gamma_f} [1 - F(\theta^+)] .$$

In the case in which home capacity is always fully used, i.e. $q_h = k$ for all θ , the two subsidies are equivalent. In that case, the subsidy s_h has no direct effect on production, and the two first order conditions obtained from the derivation of welfare $W(s_h, k(s_h, s_k))$ are equivalent, both equations amount to choosing k that cancel the derivative $\partial W / \partial k$. In that particular case the two subsidies satisfy:

$$s_h + s_k = \sigma u_f \frac{b}{b + \gamma_f} [1 - F(\theta^+)] .$$