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

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Abstract

Countries which currently are, or are in the process of, implementing a national or regional cap and trade CO2 scheme are following alternatives routes in a number of ways: coverage, cap/target, allocation of allowances, measures to manage price volatility, offsets, measures to address competitiveness and leakage. This last issue more specifically concerns “sensitive sectors”, i.e. internationally traded carbon intensive sectors (aluminium, cement, steel, refined petroleum...). Three main approaches have been proposed: output based allocation (Australia, California, New Zealand), capacity based allocation (EU) and auctioning with border adjustment. This paper investigates what the best policy should be in this setting. The analysis suggests that, if a border adjustment is not available, a combination of output and capacity based allocation is socially optimal. Demand uncertainty and international competition play a key role in the analysis since the interaction between these two factors makes the difference. A calibration of the model is used to evaluate the EU scheme for the cement sector in the third phase of the EU-ETS (2013-2020). It is shown that (i) an output based scheme would perform better than the proposed scheme, that (ii) if output-based allocation is chosen, allocation should be much less generous than the current EU benchmark, and that (iii) full auctioning with border–adjustment would perform even better.

JEL Classification: D24, L13, H23, L74
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 Bovenberg et al. 2001 for an early discussion of this objective; many articles have discussed the wind fall profits accruing to the EU industry originating from the use of a much too high benchmark for grand fathering, see for instance Smale et al., 2006). Another example of controversy is related to the use of the new entrant and closure provision. This provision has been seen as an empirical 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 ambition to set up their own national or regional ETS schemes (Australia, California, China, India, New Zealand...). The EU has implemented 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 transfer of consumption from low carbon intensive products to those products that benefit from the scheme (Quirion, 2009, Fischer and Fox, 2011).

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).

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.

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 actually 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 actual level of international competition 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 homogenous 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 the 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 of 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, the optimal scheme would be an output based scheme, mostly because of the relatively low level of demand uncertainty and the relatively high level of existing capacities. Still an important feature of this optimal scheme concerns the relatively low level of our optimal industry benchmark, compared to the existing European benchmark: we demonstrate that this 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 (Cook, 2011). 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, 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 $[\underline{\theta}, \overline{\theta}]$ 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 cost of a capacity is 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 can not be modified. We consider that $C_h(q, k)$ 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 my 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 assumed 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, the firm maximizes its profit (1) considering the price fixed. The price clears the market and the equilibrium productions satisfy the two conditions

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

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

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 $q_f(s_f, k, \theta)$. 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:

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

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

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

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:

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

and, the expected welfare is

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

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_h 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.

To subsidize production and capacity is not the first best regulation. Indeed, the first best regulation would be to tax foreign emissions, and a second best strategy would be to tax foreign production, this last solution corresponds to the border tax adjustment mechanism that was envisioned for the design of the EU-ETS but not implemented. To subsidize production via the allocation of free allowances is also a second best strategy to tackle the pollution leakage. 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*. The marginal environmental benefit from an increase of home production due to the reduction of foreign emissions is $\sigma u_f \partial \psi_f / \partial q_h$.

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

$$s_h = \sigma u_f \frac{\mathbb{E}[-\partial\psi_f/\partial q_h \, \partial q_h/\partial s_h]}{\mathbb{E}[\partial q_h/\partial s_h]} \tag{10}$$

$$s_k = \sigma u_f \mathbb{E}[-\partial\psi_f/\partial q_h \, \partial q_h/\partial k] - s_h \mathbb{E}[\partial q_h/\partial k]. \tag{11}$$

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 is*

$$s_h = \sigma u_f \frac{\partial\psi_f}{\partial q_h} \tag{12}$$

and the capacity subsidy is null.

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 $\partial\psi_f/\partial q_h$. Note that, if u_f is very large this subsidy could be higher than σu_h the cost of emissions per output. 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. With demand uncertainty the sensitivity of foreign production to home production depends upon the demand state. Consequently, a benevolent, welfare maximizing, 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 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),

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

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 rational 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 correlation is essential as is illustrated by the following Proposition.

Proposition 2 *If the three following conditions hold:*

- *the sensitivity of imports to home production is increasing w.r.t.* θ*,*
- *the effect of the subsidy on the home production is decreasing w.r.t.* θ *and,*
- *the effect of the capacity on the home production is increasing w.r.t. to* θ*,*

then,

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

Proof. From 11 and 10

$$\frac{s_k}{\sigma u_f} = cov(\frac{\partial \psi_f}{\partial q_h}, \frac{\partial q_h}{\partial k}) - cov(\frac{\partial \psi_f}{\partial q_h}, \frac{\partial q_h}{\partial s_h}) \frac{\mathbb{E}[\partial q_h / \partial k]}{\mathbb{E}[\partial q_h / \partial s_h]} \tag{15}$$

From the two first assumption $cov(\partial \psi_f / \partial q_h, \partial q_h / \partial s_h)$ is negative and from the first and third assumption $cov(\partial \psi_f / \partial q_h, \partial q_h / \partial k)$ is positive. Therefore, the difference between the later and the former is positive, so is s_k.

The second result comes from 13 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:

$$C_h(q,k) = \begin{cases} c_h q & if\ q < k \\ c_h q + 0.5\gamma_h (q-k)^2 & otherwise \end{cases} \tag{16}$$

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. 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.,

$$C_f(q_f) = c_f q_f + 0.5\gamma_f q_f^2. \tag{17}$$

It is further assumed that for all situations considered imports are more costly than home production:

$$c_f > c_h + \sigma u_h - s_h. \tag{18}$$

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 θ^- and θ^+ two threshold states 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 supply curve and the short term equilibrium in the three regimes is depicted in Figure (1).

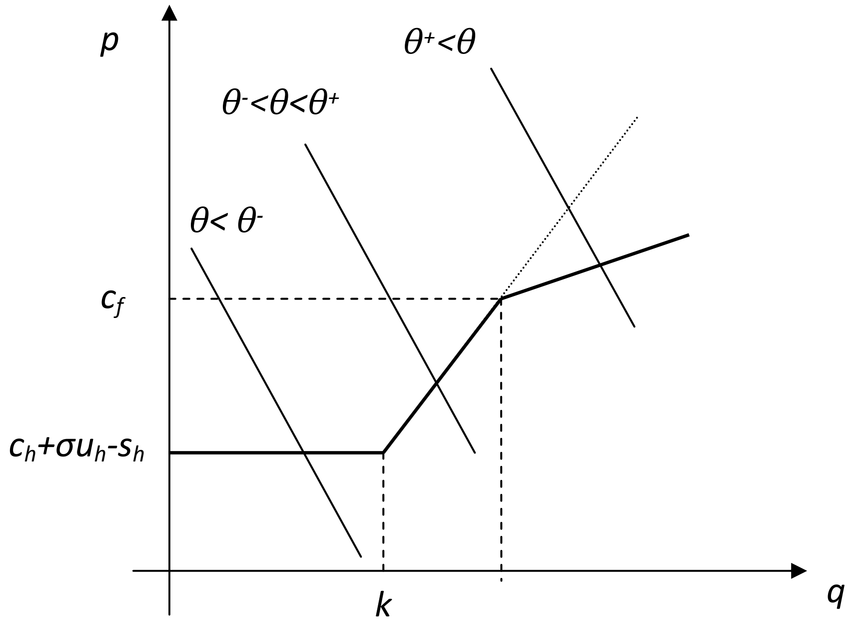

Figure 1: Price function and short term production

In the short term, with the quadratic cost 18, 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:

$$\int_{\underline{\theta}}^{\theta^-} 0 dF(\theta) + \int_{\theta^-}^{\bar{\theta}} \gamma_h(q_h - k) dF(\theta) = \mathbb{E}[p + s_h - c_h - \sigma u_h] = c_k - s_k. \quad (19)$$

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 strictly lower than the 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 and the sensitivity of imports to home production and the effect of capacity on home production in the three regimes (cf Appendix). 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. The expressions of the optimal couple of subsidies is

$$s_h = \sigma u_f \frac{b}{b+\gamma_f} \frac{1-F(\theta^+)}{1-F(\theta^+)+A} \tag{20}$$

$$s_k = s_h \frac{\gamma_h}{b} F(\theta^-), \tag{21}$$

where

$$A = \left[\gamma_h + \gamma_f \frac{b}{b+\gamma_f}\right] \left[\frac{F(\theta^-)}{b} + \frac{F(\theta^+) - F(\theta^-)}{b+\gamma_h}\right]. \tag{22}$$

In this specification the conditions of Proposition 2 are not fully satisfied, but still, 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 imports in those states; they correspond to states in which the regulator would set a null subsidy if it were possible. The production subsidy is distorsive 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 2 *The optimal subsidy on capacity is positive if 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 (20) is worth some attention. The rate of free allocation per production unit (for the output based component of the scheme) should be

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

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 last 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 could 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 correspond 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 correspond 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, and because imports might not occur in all demand states.

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 3 *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 CO_2/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 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 important features of the cement market, such as imperfect competition and geographic differentiation, but we are confident that our main results would remain in a more complex model including these features, such as Demailly and Quirion (2006, 2008) or Ponssard and Walker (2008).

4.1 Calibration and parameter values in the central scenario

The model is calibrated using data from 2007–2009. Year 2007 is a peak for cement consumption in the EU while 2009 is a recession year. These two years are used as representative for a 2020 horizon. In view of the maturity of the EU cement sector, this assumption seems reasonable. In peak years, production and imports are high while in recession years they are low (Cook, 2011).

As will be detailed later on, the scheme to be adopted for the EU-ETS 2013-2020 concerns clinker and not cement. Except otherwise specified our numerical values are for clinker.

Table 1 below presents the parameters and the value of key variables in the No-Policy scenario. To specify the probability distribution function of the demand state theta, we assume that it can take, with an equal probability, two states. We take 2007 as the high demand case and 2009 as the low demand case. We estimate clinker production from the cement production data provided by the European cement manufacturer association activity reports (Cembureau 2007, 2009) and the clinker/cement ratio of the WBCSD CSI GNR database.[2]

Unfortunately, there is no publicly available clinker price data. To overcome this problem, we compute a clinker unit value from the UN Comtrade database[3] by dividing the value of EU imports by their volume. This

[1] More precisely, to the EU grey clinker market. Clinker is the CO_2-intensive intermediary product used to manufacture cement, and grey clinker is by far the dominant variety of clinker. We model clinker rather than cement because it is more CO_2-intensive and less costly to transport than cement, so if carbon leakage takes place in the cement sector, it should be through clinker trade rather than through cement trade. Moreover, the EU ETS regulation is on clinker and not on cement.

[2] http://www.wbcsdcement.org/index.php?option=com_content\&task=view\&id=57\&Itemid=118

[3] http://comtrade.un.org/db/

database also provides the volume of imports. We do not take into account clinker exports from the EU because they are usually very low.

The slope of the demand curve is set at 2 Mt./(€/t.) which brings a price elasticity of demand between -0.5 and -1, i.e. in the range of published estimates, whatever the state of demand and the policy scenario.[4]

A more difficult parameter to estimate is the production from new plants. Firstly, there is no published estimate of new clinker capacities since Cembureau stopped publishing plant-level data in 2002.[5] 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 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 CO_2 price, in order to find the parameters that are consistent with the above-mentioned data. The values of the (calibrated) 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,[6] a profit margin and all the administrative costs incurred by the authorization procedure to operate a new clinker plant in Europe.

The last parameters, described in the last section of Table 1, are linked to emissions and abatement. We make the following additional and simplifying assumption. Firstly, all EU plants have the same specific emissions,[7] and all foreign plants have the same specific emissions, but specific emissions of EU and foreign plants differ. Secondly, the marginal abatement cost curve is linear: every extra €/t CO_2 brings the same extra abatement per tonne of clinker. Thirdly, the abatement cost is 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

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

[5]Admittedly, 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.

[6]In 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.

[7]Admittedly, some plants emit more than others, with specific emissions in the EU ranging from ca. 750 to ca. 1150 kg CO_2/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 at our knowledge.

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%.

Data used for calibration		
Variable	**Value**	**Source**
Demand curve slope (1/b)	2 Mt/(€/t)	Own estimation
Clinker price (high demand - hd)	80€/t	UN Comtrade (2007)
Clinker price (low demand - ld)	60€/t	UN Comtrade (2009)
Production from existing plants (h.d.)	220 Mt/yr	Cembureau (2007)

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)

Other parameters		
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)	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

Table 1: Model parameters and key values in the No-Policy scenario

4.2 The allocation mechanism in EU-ETS for 2013-2020 the cement sector[8]

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 CO_2/t. clinker; it was calculated as the average specific emissions of the 10% most CO2-efficient clinker kilns in the EU.

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. Consequently, in the rest of the paper, we assume that the closure rule in ineffective, so allocation to existing firms is, economically, a lump-sum transfer.

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.

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

Our six scenarios are the following:

1. **No-Policy**: no climate policy.

[8]This section is largely based on Quirion et al. (2009).

2. **Auctioning**: full auctioning, no recycling of auction revenues. In other words, auction revenues are used to reduce public deficits.

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, following the EU-ETS phase III rules that will apply from 2013 onwards (European Commission, 2010). According to these rules, for each tonne of grey clinker annual production capacity, a new plant receives the EU-ETS benchmark (0.766 tonne CO_2/tonne clinker) multiplied by a utilization rate yet to be defined, but we compute this scenario for various amounts 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. This lump-sum transfer has no economic impact except that it reduces public revenues from carbon pricing and increases firms' profits: since it is not linked to firms decisions, it does not change production, price, investment or abatement. The lump-sum transfer is calculated so that the total allowance allocation to firms (New entrants reserve + lump-sum allocation) equals their expected emissions. In other words, in average, firms are neither sellers nor buyers. In addition, we assume that the closure rules (see introduction above) are not effective.

5. **OBA** (Output-Based Allocation): for every tonne of grey clinker produced in the EU, firms receive a given number of allowances.

6. **Border Adjustment** (with full auctioning, no revenue recycling): To be allowed to export into the EU, foreign firms have to pay the CO_2 price times an adjustment factor.

4.4 Results

Figure 2 shows the welfare variation compared to the No-Policy scenario, in percentage. As explained above, the optimal policy is the border adjustment with an adjustment factor equal to specific emissions in the rest of the world $u_f = 0.852$ t. CO_2/t. clinker. Note that the curve is flat on the top so with a lower adjustment set at the level of the EU benchmark, 0.766 t. CO_2/t. clinker, as proposed by Monjon and Quirion (2010), welfare would be almost as high.

Although less interesting than border adjustment, OBA brings a higher welfare than Auctioning if not too generous. As shown in equation (20) above, the optimal allocation is $u_f b/(b + \gamma_f)$ i.e., in this numerical application, one third of specific emissions in the rest of the world u_f, or 0.284 t. CO_2/t. clinker. Yet if the allocation is too generous, e.g. if it reaches the EU benchmark, welfare is lower than under Auctioning. This non-monotonous impact of OBA on welfare comes from two mechanisms: one the one hand, welfare increases due to a lower leakage, but on the other hand it is reduced because OBA entails too high a production of polluting goods.

Capacity-based allocation (NER & EU-ETS) has the same impact as Auctioning if the allocation rate per tonne of clinker capacity installed is low, because no investment in new plants take place anyway, which is also the case under Auctioning. If the allocation rate is higher than 0.204 CO_2/t. clinker, new capacity is installed and the impact on welfare is negative. This is because in this numerical application, even in the low demand state, home production is higher than new capacity (cf. corollary 2 above). Welfare with an optimal OBA scheme would be 5% higher than welfare with the current EU-ETS.

This synthetic comparison is worth reviewing in details according to more specific criteria.

Figure 3 shows 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. It reaches 22% under Auctioning, less than the values obtained by Demailly and Quirion (2006) as well as by Ponssard and Walker (2008) but more than those obtained by Monjon and Quirion (2011a, 2011b) for the cement sector. The ratio is lower under border adjustment, and negative (i.e. foreign emissions decrease) if the adjustment is higher than 0.7 t. CO_2/t. clinker. 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.

OBA also yields a lower leakage ratio than Auctioning, and this ratio becomes negative for a generous enough allocation. In this case, firms are net sellers of allowances. For an allocation equal to the EU benchmark, the ratio is only 3%, but for the optimal allocation corresponding to equation 20, it reaches 19%, not much below the figure for Auctioning.

Under NER and EU-ETS, the leakage ratio is the same as under Auctioning if the allocation rate is too low to generate investment, but converges with that of OBA if the allocation is generous enough.

Examining the leakage-to-reduction ratio,[9] it may seem that OBA, NER and EU-ETS are environmentally more efficient than Auctioning, but this conclusion would neglect the fact that we compare scenarios for a given CO_2 price, not for a given level of European emissions – and the latter are higher for OBA, NER and EU-ETS, because then clinker production is

[9] We consider the ratio of expected leakage to expected reduction of home emissions. For a discussion on the distinction between this ratio, the conditional ratio and the expected ratio see Meunier and Ponssard (2012).

higher. Figure 4 displays the emissions due to EU consumption, i.e. the sum of European emissions and emissions entailed by the production of clinker exported into the EU. Emissions from EU consumption is lower with Border adjustement than with Auctioning, but under OBA, NER and EU-ETS they are larger for all values of free allocations considered. This comparison illustrates that even though it is rational, on welfare ground, to subsidize home production in order to limit leakage it is not necessarily good for the environment.

An important issue for climate policies acceptability is its impact on firms' profit (Figure 5), since a policy with a severe negative expected impact on profit is unlikely to survive the policy process. Under Auctioning, expected profit decreases by 16%, which explains why cement firms have intensively lobbied against such a scenario in the context of the EU-ETS revision in 2008. Border adjustment and OBA mitigate the profit loss, which vanishes under OBA if the allocation is high enough to generate new investments. In this case, expected profit from existing firms is unaffected because the direct effect of the CO_2 price of existing firms' profit is compensated by a change in the amount of new production capacities, which impacts the clinker price.

The impact of NER and EU-ETS on expected profit is more puzzling. Why are profits reduced by the new entrant reserve, which constitutes a subsidy to firms? The reason is that this subsidy triggers new investments —this is its very purpose— and these investments reduce the clinker price. Existing plants still have to pay for their emissions, but while with Auctioning the clinker price increases by 17% (Figure 6), it rises less under NER and EU-ETS. In other words, the application of a new entrant reserve prevents firms from passing the majority of the allowance cost on to consumers. However, under EU-ETS, the lump-sum transfer to existing plants compensates the negative impact of the NER on profits. If the NER is not too generous and the lump-sum transfer is high, firms benefit from a windfall profit, i.e. their profit is higher than in the No-Policy scenario – much higher in this case, up to +42%. This result is in line with previous assessments of lump-sum transfers, e.g. by Bovenberg et al. (2008) or, in the context of the cement sector, Demailly and Quirion (2006).

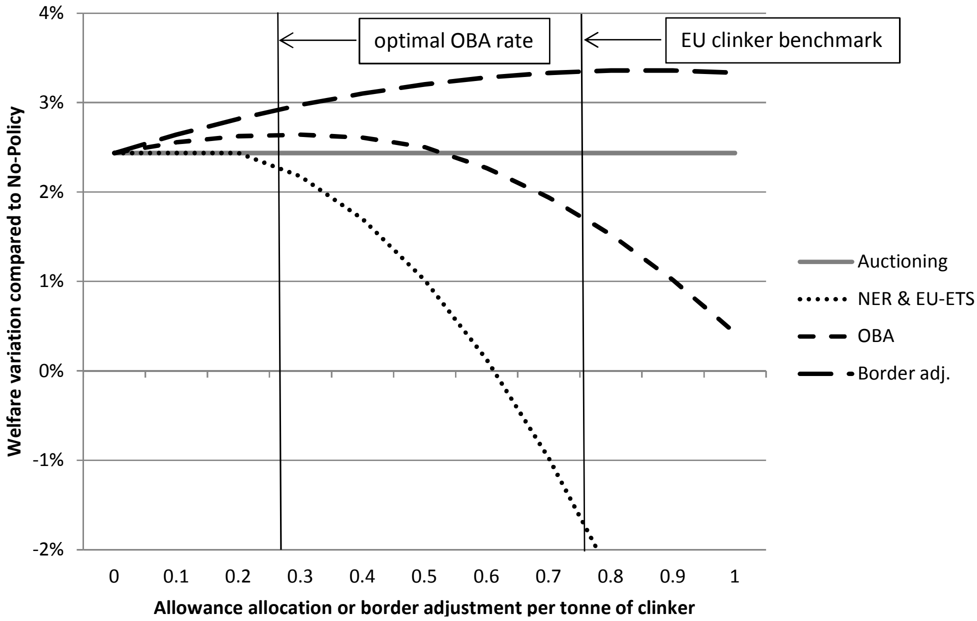

Figure 2: Welfare compared to No-Policy. For border adjustment, the x-axis represents the adjustment factor, i.e. the number of allowances to be paid for one tonne of cement exported into the EU. For OBA, it represents the number of allowances received per tonne of clinker produced. For NER & EU-ETS, it represents the number of allowances received per tonne of clinker capacity installed.

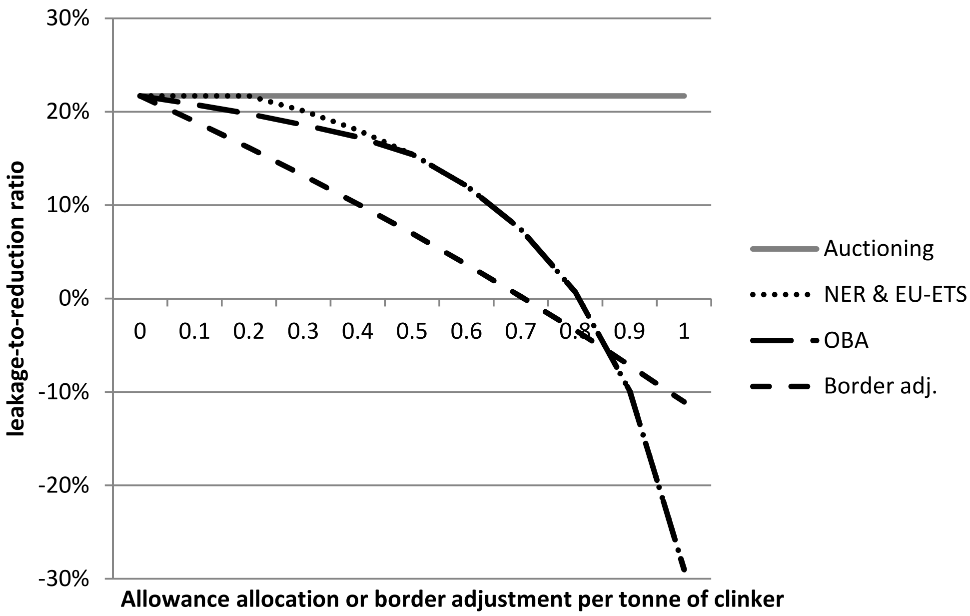

Figure 3: Leakage-to reduction ratio.

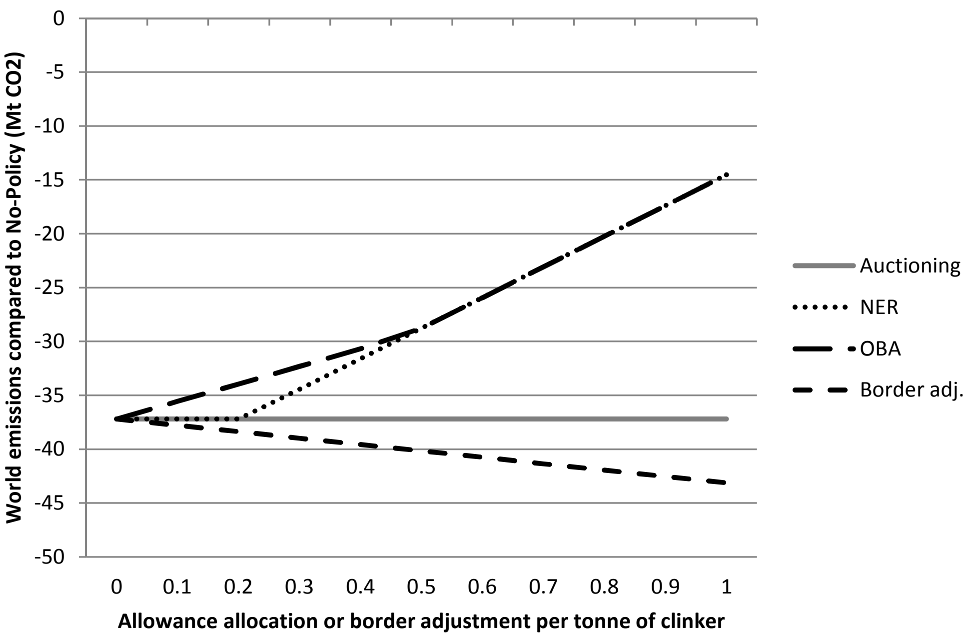

Figure 4: Emissions due to EU consumption compared to No-Policy

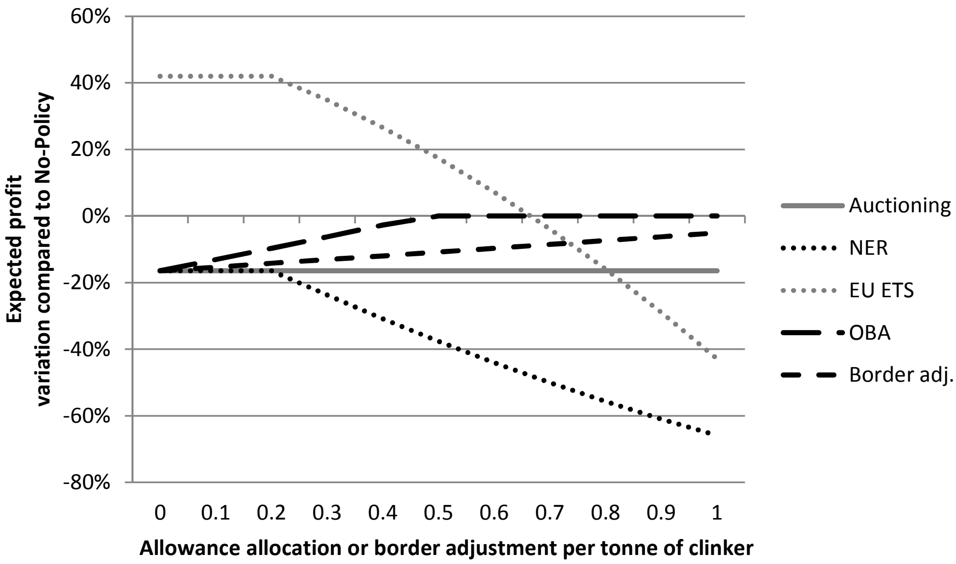

Figure 5: Expected profits compared to No-Policy.

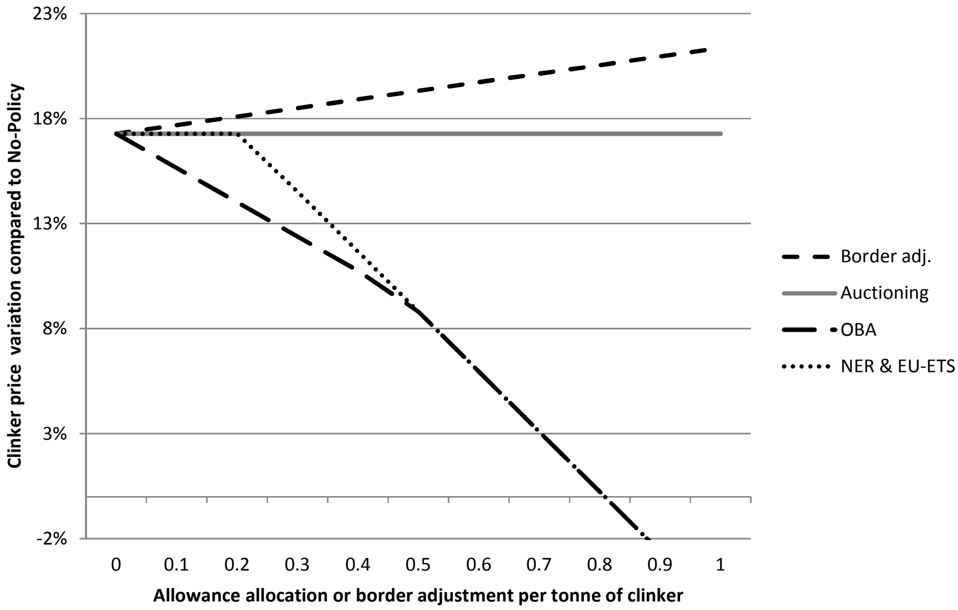

Figure 6: Expected price compared to No-Policy.

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. 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 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.

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. The differences in terms of profit loss, leakage ratio, and cement prices are discussed.

Our analysis has also relevance for the other ETS that will be implemented in the near future such as in Australia or in California. In both cases, these countries selected an output based scheme while in the EU a capacity based scheme had been selected. Still these output based schemes set production subsidies at a very high level compared from what our theoretic analysis would suggest.

Admittedly our analytical framework remains quite simple. For instance our model does not introduce industry specificities such as the oligopolistic structure, the role of geography, of multi plant ownership, nor a proper dynamic schedule to allow for the explicit life time of cement plants. Still it integrates an important feature that had been totally absent in previous economic analyses 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 and their long term implications in terms of relocation of investments. We believe that this paper is a useful and interesting step into that direction.

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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:

$$\frac{\partial W}{\partial k}\frac{\partial k}{\partial s_k} = 0 \text{ and } \frac{\partial W}{\partial s_h} + \frac{\partial W}{\partial k}\frac{\partial k}{\partial s_h} = 0 \tag{23}$$

which are equivalent to the couple of equations:

$$\frac{\partial W}{\partial k} = 0 \text{ and } \frac{\partial W}{\partial s_h} = 0. \tag{24}$$

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),

$$\left[\frac{\partial w}{\partial q_h} + \frac{\partial w}{\partial q_f}\frac{\partial \psi_f}{\partial q_h}\right]\frac{\partial q_h}{\partial s_h} = [-s_h - \sigma\partial\psi_f\partial q_h]\frac{\partial q_h}{\partial s_h}. \tag{25}$$

Therefore, the first order condition is :

$$\mathbb{E}\left[(-s_h - \sigma\partial\psi_f\partial q_h)\frac{\partial q_h}{\partial s_h}\right] = 0 \tag{26}$$

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

$$\frac{\partial W}{\partial k} = \mathbb{E}[(\frac{\partial w}{\partial q_h} + \frac{w}{\partial q_f}\frac{\psi_f}{\partial q_h})\frac{\partial q_h}{\partial k}] - \mathbb{E}[\frac{\partial C_h(q_h,k)}{\partial k}] - c_k \tag{27}$$

$$= \mathbb{E}[(-s_h + \sigma u_f\frac{\psi_f}{\partial q_h})\frac{\partial q_h}{\partial k}] - s_k \tag{28}$$

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 $p < \partial C_f/\partial q_f$, 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

$$q_h = [(a + \theta) - (c_h + \sigma u_h - s_h)]/b. \tag{29}$$

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

$$q_h = [(a+\theta) - (c_h + \sigma u_h - s_h - \gamma_h k)]/[b + \gamma_h]. \tag{30}$$

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

$$\psi_f = [a + \theta - bq_h - c_f]/[b + \gamma_f], \tag{31}$$

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

$$q_h = \left[(a+\theta) + \frac{b}{\gamma_f}c_f - (1 + \frac{b}{\gamma_f})(c_h + \sigma u_h - s_h + \gamma_h k)\right]\left[b + \gamma_h(1 + \frac{b}{\gamma_f})\right]^{-1} \tag{32}$$

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 (30).

Subsidies

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

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

and

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

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 (20) with the expression (22) of A.

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

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

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 (21).

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 :

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

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)

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

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:

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