

# The carbon leakage effect on the cement sector under different climate policies

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## Abstract

The European emissions trading scheme (EU-ETS) is a cap and trade system that requires the industries participating in the program to obtain allowances to cover their carbon emissions. Energy Intensive Industries claim that this system puts their European plants at an economics disadvantage compared to facilities located outside the EU. As a direct consequence, industries may relocate their production activities in unregulated countries, leading to the so-called carbon leakage effect. In order to curb this effect, several policies have been devised, including grandfathering of CO<sub>2</sub> allowances and border tax adjustment. This paper investigates the impact of these two policies on the cement sector, with a particular focus on the Italian market, particularly prone to carbon leakage. The analysis is based on an oligopolistic partial equilibrium model with a detailed technological representation of the market. The model is a Generalized Nash Equilibrium Problem that accounts for the interactions of cement companies. Simulations show that neither the grandfathering nor the border tax adjustment fully solve the carbon leakage problem because cement companies modify their cement and clinker trade strategies according to the measure applied in order to avoid or reduce their carbon costs.

**Keywords:** Carbon leakage, Cement industry emissions, EU Emissions Trading Scheme, Environmental policies, Generalized Nash Equilibrium Problem.

## 1 Introduction

The EU-ETS is a cap and trade system, applied in Europe since 2005, that limits CO<sub>2</sub> emissions generated by power and specific industrial installations. This CO<sub>2</sub> regulation causes additional costs for the Energy Intensive Industries (EIIs) operating these installations. These additional costs may affect EIIs' competitiveness on international markets and the effect may be relevant for some particular sectors (see Droege, 2012).

As a consequence, EIIIs are threatening to relocate part of their activities in countries where environmental regulations are not applied or are less restrictive for protecting their competitiveness. The relocation of production activities would imply a transfer of CO<sub>2</sub> emissions as well, leading to the so-called “carbon-leakage” phenomenon. The sectors that are exposed to carbon leakage generally consist of multinational companies operating worldwide. These companies hence could relocate part of their production without suffering dramatic economic losses themselves. This is especially the case of metals and cement industries. European cement industries have been amongst the most important supporters of the competitiveness and carbon leakage debate. Different policy measures have been proposed to address this issue. These include *free allowance allocation (FA)* and *border tax adjustment (BTA)*. The first remedy was imposed by Directive 2003/87/EC for the period 2005-2012. Allowance grandfathering to those EIIIs “exposed to a significant risk of carbon leakage” became matter of discussion during the period of settlement of the third ETS phase (2013-2020). The need to protect the competitive position of the EU industry has accordingly been taken into account in the design of the Directive 2009/29/EC regulating the third ETS phase<sup>1</sup>. The European Commission has issued a list of all sectors that are deemed to be subject to the risk of carbon leakage and cement sector is one of them<sup>2</sup>. The application of the *BTA* policy aims at mitigating the carbon leakage effect by supporting EU EIIIs’ exports and taxing their imports from countries with a more lenient (or no) environmental system<sup>3</sup>. Note that this policy is applied in addition to the free allowance allocation. We analyze whether the application of the *FA* and *BTA* policies can mitigate carbon leakage and the loss of competitiveness of cement sector. Several studies (Boston Consulting Group, 2008a; Demailly and Quirion, 2008; Linares and Santamaria, 2012; Ponssard and Walker, 2008; Reinaud 2008, 2009) show that the carbon leakage effect in the cement sector depends on the location of the plants and on transportation costs. Cement and clinker trade is characterized by high land (road and rail) transportation costs. Ship transport is much cheaper and its economic efficiency increases with the distance. For this reason, coastal plants (and countries) have a higher incentive to relocate their clinker/cement production than inland plants. This implies that the geographical distribution of EU plants affects relocation strategies. The major contribution of this paper is the development of an international spatial oligopolistic model based on a technological representation of the cement market that describes clinker and cement production processes in different world countries with a particular focus on the Italian market. We assume that companies are Cournot players that maximize their profit simultaneously, since their strategies are interrelated by the market clearing conditions, common to all the companies. We measure their carbon leakage exposure by monitoring their cement and clinker exchanges between environmentally regulated and unregulated areas. From a math-

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<sup>1</sup>Specifically, point 12 of Article 10a states that “in 2013 and in each subsequent year up to 2020, installations in sectors or subsectors which are exposed to a significant risk of carbon leakage shall be allocated, pursuant to paragraph 1, allowances free of charge at 100% of the quantity determined in accordance with the measures referred to in paragraph 1” See: <http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF>

<sup>2</sup>The first carbon leakage list (available at <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:001:0010:0018:EN:PDF>) was adopted by the European Commission at the end of 2009 and is applicable for the free allocation of allowances in 2013 and 2014. It has to be updated every five years. The Commission will determine the next list by the end of 2014, which will apply for the years 2015-2019.

<sup>3</sup>See Monjon and Quirion (2010) and references therein and Cook (2011b) for a comprehensive discussion on *BTA* applied to the cement sector.

emtical point of view, we model this problem as a Generalized Nash Equilibrium Problem (GNEP)<sup>4</sup>. The model is reformulated as a Mixed Complementarity Problem (MCP)<sup>5</sup> and implemented in GAMS using the PATH solver. The paper is organized as follows. Section 2 presents the developed models; Sections 3 and 4 respectively describe the dataset and the results of our simulations. Section 5 reports our final remarks.

## 2 The cement market model

We develop a partial equilibrium model for investigating the carbon leakage and the effectiveness of the *FA* and *BTA* policies. Our model describes an international cement market subdivided into zones with and without environmental regulation. Each zone is further partitioned into coastal and inland regions to better investigate the impacts of the *FA* and *BTA* policies on the basis of the geographical distribution of the different plants. To this aim, we provide a technological representation of the cement market that accounts for all production phases (raw material extraction, clinker and cement production). Note that clinker can be produced using different technologies (dry, semi-dry, semi-wet, wet) in full-cycle plants or can be bought from other competitors in the same or in other zones. Each company can then produce clinker for its own needs or sell it to other companies located in different zones. Finally, cement and CO<sub>2</sub> allowances prices are endogenously determined in the model.

### 2.1 Notation

We first list the sets, the parameters and the variables used in our models.

#### Sets

$J$	Set of cement companies operating in the market.
$I$	Set of zones in which the market is divided. We define $I = I_{ETS} \cup I_{NETS}$ , where $I_{ETS}$ includes all zones subject to the EU-ETS while $I_{NETS}$ indicates those zones without environmental regulation. Each zone $i \in I$ can be further partitioned in $\hat{l}$ homogeneous regions that we indicate as $i_1, i_2, \dots, i_{\hat{l}}$ . We denote $Z_i = \{i_l : l \in L\}$ , where $L = \{1, \dots, \hat{l}\}$ , for all $i \in I$ . For example $l = 1, 2$ distinguish between coastal and inland regions in each zone $i \in I$ .
$W$	Set of technologies used for producing clinker.
$V$	Set of technologies used for producing cement.
$G$	Set of fuel employed in clinker production.

<sup>4</sup>See Facchinei and Kanzow (2007) and Pang and Fukushima (2005) for more details on GNEP and its possible applications.

<sup>5</sup>See Facchinei and Pang (2003).

$N_{j,i_l}$	Set of plants of company $j \in J$ located in the region $i_l \in Z_l$ , where $i \in I$ and $l \in L$ .
$W_n$	Set of clinker technologies available in plant $n \in N_{j,i_l}$ .
$V_n$	Set of cement technologies available in plant $n \in N_{j,i_l}$ .

### Parameters

$t_{j,i_l,h_r}^k$	Clinker transportation cost sustained by company $j \in J$ to move clinker from region $i_l \in Z_l$ to region $h_r \in Z_h$ .
$p_i^{mk}$	Price of the stones (limestone, chalk, marl and shale) in zone $i \in I$ used as raw material for producing clinker.
$\gamma_{g,i,w}^k$	Proportion of fuel $g \in G$ used in clinker production in zone $i \in I$ , with technology $w \in W$ (ton/ton).
$p_{g,i}^f$	Price of fuel $g \in G$ in zone $i$ used in clinker production.
$\alpha_w$	Electricity consumption per tons of clinker produced with technology $w \in W$ (KWh/ton).
$Q_{n,w}^k$	Capacity of the kiln of technology $w \in W_n$ of plant $n \in N_{j,i_l}$ .
$p_i^k$	Price of clinker for each zone $i \in I$ (euro/ton).
$\rho_i$	Clinker to cement ratio applied in zone $i \in I$ (%).
$\sigma_i$	Raw material to clinker ratio applied in zone $i \in I$ (%).
$t_{j,i_l,h_r}^c$	Cement transportation cost sustained by company $j \in J$ to move cement from region $i_l \in Z_l$ to region $h_r \in Z_r$ .
$p_i^{mc}$	Price of the material (gypsum, slag, limestone) used for producing cement in zone $i \in I$ .
$Q_{n,v}^c$	Grinding mill capacity of technology $v \in V_n$ of plant $n \in N_{j,i_l}$ .
$\beta_v$	Electricity consumption per tons of cement produced with technology $v \in V$ (KWh/ton).
$p_i^e$	Average electricity price in zone $i \in I$ .
$p^{CO_2}$	Allowance price (€/ton CO <sub>2</sub> ).
$GA_{n,w}$	Amount of grandfathered allowances for plant $n \in N_{j,i_l}$ with technology $w \in W_n$ (ton/year).

$CAP$	Total emission cap imposed in the market considered for cement plants covered by the EU-ETS (ton/year).
$\tau_{i,w}$	Average emission factor per ton of clinker produced depending on the zone $i \in I$ and technology $w \in W$ .

### Variables

$q_{n,w}^k$	Clinker produced by plant $n \in N_{j,i_l}$ with technology $w \in W_n$ (ton/year).
$s_{j,i_l,\bar{j},h_r}^k$	Clinker produced by company $j \in J$ in region $i_l \in Z_l$ and sold to company $\bar{j} \in J, \bar{j} \neq j$ , in region $h_r \in Z_h$ (ton/year).
$b_{j,i_l,\bar{j},h_r}^k$	Clinker bought by company $j \in J$ to satisfy demand in region $i_l \in Z_l$ from company $\bar{j} \in J, \bar{j} \neq j$ , in region $h_r \in Z_h$ (ton/year).
$u_{j,i_l}^k$	Clinker produced by company $j \in J$ in region $i_l \in Z_l$ and used in the same region (ton/year).
$m_n^k$	Raw material (limestone, chalk, marl and shale) used by plant $n \in N_{j,i_l}$ to produce clinker (ton/year).
$e_n^k$	Electricity used by plant $n \in N_{j,i_l}$ to produce clinker (KWh/year).
$f_{g,n,w}^k$	Fuel of type $g \in G$ used by plant $n \in N_{j,i_l}$ to produce clinker with technology $w \in W_n$ (ton/year).
$q_{n,v}^c$	Cement produced by plant $n \in N_{j,i_l}$ with technology $v \in V_n$ (ton/year).
$s_{j,i_l,h_r}^c$	Cement produced by company $j \in J$ in region $i_l \in Z_l$ and sold in region $h_r \in Z_h$ (ton/year).
$e_n^c$	Electricity used by plant $n \in N_{j,i_l}$ to produce cement (KWh/year).
$m_n^c$	Material (gypsum, slag, limestone) used by plant $n \in N_{j,i_l}$ to produce cement (ton/year).

In the following subsections, we will indicate in parentheses, next to each constraint, the corresponding dual variable.

## 2.2 Clinker and cement producers' model

We consider a static optimization problem, based on a time-window of one year, corresponding to the frequency at which the surrender of emission allowances is due. In this short time framework, we assume neither new company entrance nor company failure. Taking into account that the market structure in the cement industry is mainly oligopolistic, we provide the mathematical formulation of the producers problem

according to the hypothesis that suppliers can exercise market power and alter the cement price by changing the amount they sell. We then represent the model as a *Cournot* game among cement producers where the regional cement price  $P_{i_l}^c$  is defined as a function of the total quantity of cement sold in the market as indicated in (1):

$$P_{i_l}^c = P_{i_l}^c \left( \sum_{j \in J, h_r \in Z_h, h \in I} s_{j, h_r, i_l}^c \right), \quad i_l \in Z_i, i \in I \quad (1)$$

In this context, any cement company  $\hat{j} \in J$  maximizes its objective function  $\theta_{\hat{j}}$ , taking into account several technological constraints:

$$\begin{aligned} & \left( \mathcal{M}_{\hat{j}} \right) && \text{Max} && \theta_{\hat{j}} \\ & && \text{s.t.} && \Xi_{\hat{j}} \end{aligned}$$

where  $\Xi_{\hat{j}}$  denotes the set of constraints. More specifically, each producer  $\hat{j} \in J$  maximizes its profit function  $\theta_{\hat{j}}$ :

$$\theta_{\hat{j}} = \sum_{h_r \in Z_h, h \in I} P_{h_r}^c \cdot \sum_{i \in I, i_l \in Z_i} s_{\hat{j}, i_l, h_r}^c - \sum_{\substack{i, h \in I, i_l \in Z_i, \\ h_r \in Z_h}} s_{\hat{j}, i_l, h_r}^c \cdot t_{\hat{j}, i_l, h_r}^c \quad (2)$$

$$+ \sum_{\substack{i, h \in I, h_r \in Z_h, \\ i_l \in Z_i, j \in J, j \neq \hat{j}}} p_h^k \cdot s_{\hat{j}, i_l, j, h_r}^k - \sum_{\substack{i, h \in I, h_r \in Z_h, \\ i_l \in Z_i, j \in J, j \neq \hat{j}}} (p_i^k + t_{\hat{j}, h_r, i_l}^k) \cdot b_{\hat{j}, i_l, j, h_r}^k \quad (3)$$

$$- \sum_{\substack{i \in I, i_l \in Z_i, \\ n \in N_{\hat{j}, i_l}}} p_i^{mk} \cdot m_n^k - \sum_{\substack{i \in I, i_l \in Z_i, \\ n \in N_{\hat{j}, i_l}}} p_i^{mc} \cdot m_n^c \quad (4)$$

$$- \sum_{\substack{g \in G, i \in I, i_l \in Z_i, \\ n \in N_{\hat{j}, i_l}, w \in W_n}} p_{g, i}^f \cdot f_{g, n, w}^k - \sum_{\substack{i \in I, i_j \in Z_i, \\ n \in N_{\hat{j}, i_l}}} p_i^e \cdot (e_n^k + e_n^c) \quad (5)$$

taking into account the following constraints:

$$\sum_{n \in N_{\hat{j}, i_l}, v \in V_n} q_{n, v}^c = \sum_{h \in I, h_r \in Z_h} s_{\hat{j}, i_l, h_r}^c \quad (\lambda q_{\hat{j}, i_l}^c) \quad (6)$$

$$m_n^c = \sum_{v \in V_n} (1 - \rho_i) \cdot q_{n, v}^c \quad (\lambda m_n^c) \quad (7)$$

$$\sum_{n \in N_{\hat{j}, i_l}, w \in W_n} q_{n, w}^k = u_{\hat{j}, i_l}^k + \sum_{\substack{j \in J, j \neq \hat{j} \\ h \in I, h_r \in Z_h}} s_{\hat{j}, i_l, j, h_r}^k \quad (\lambda s_{\hat{j}, i_l}^k) \quad (8)$$

$$\sum_{\substack{j \in J, n \in N_{\hat{j}, i_l}, \\ v \in V}} \rho_i \cdot q_{n,v}^c = \sum_{j \in J} u_{j, i_l}^k + \sum_{\substack{j, \bar{j} \in J, j \neq \bar{j}, \\ h \in I, h_r \in Z_h}} b_{j, i_l, \bar{j}, h_r}^k \quad (\lambda q_{i_l}^k) \quad (9)$$

$$b_{j, h_r, j', i_l}^k = s_{j', i_l, j, h_r}^k, \quad j \neq j' \quad (\lambda b s_{j', i_l, j, h_r}^k) \quad (10)$$

$$\sum_{i \in I, i_l \in Z_i} u_{\hat{j}, i_l}^k + \sum_{\substack{j \in J, j \neq \hat{j} \\ i \in I, i_l \in Z_i \\ h \in I, h_r \in Z_h}} b_{\hat{j}, i_l, j, h_r}^k = \sum_{\substack{i \in I, i_l \in Z_i \\ n \in N_{\hat{j}, i_l}, v \in V_n}} \rho_i \cdot q_{n,v}^c \quad (\lambda b_{\hat{j}}^k) \quad (11)$$

$$Q_{n,w}^k - q_{n,w}^k \geq 0 \quad (\lambda Q_{n,w}^k) \quad (12)$$

$$Q_{n,v}^c - q_{n,v}^c \geq 0 \quad (\lambda Q_{n,v}^c) \quad (13)$$

$$m_n^k = \sum_{w \in W_n} \sigma_i \cdot q_{n,w}^k \quad (\lambda m_n^k) \quad (14)$$

$$e_n^k = \sum_{w \in W_n} \alpha_w \cdot q_{n,w}^k \quad (\lambda e_n^k) \quad (15)$$

$$e_n^c = \sum_{v \in V_n} \beta_v \cdot q_{n,v}^c \quad (\lambda e_n^c) \quad (16)$$

$$f_{g,n,w}^k = \gamma_{g,i,w}^k \cdot q_{n,w}^k \quad (\lambda f_{g,n,w}^k) \quad (17)$$

The objective function  $\theta_{\hat{j}}$  is composed of five main addends. The addend (2) defines producer  $\hat{j}$ 's total revenues from selling cement ( $s_{j, i_l, h_r}^c$ ) at the destination price  $P_{h_r}$ . We assume that the revenues are net of the cement transportation costs ( $s_{j, i_l, h_r}^c \cdot t_{j, i_l, h_r}^c$ ). The addend (3) refers to clinker exchanges between company  $\hat{j}$  and all other companies. In particular, it accounts for both the revenues of selling clinker ( $p_h^k \cdot s_{j, i_l, j, h_r}^k$ ) and the costs of buying clinker ( $(p_i^k + t_{j, h_r, i_l}^k) \cdot b_{j, i_l, j, h_r}^k$ ), including transportation costs. In our model, we assume that transportation costs are charged to clinker buyers. For this reason, they are associated to the variable  $b_{j, i_l, j, h_r}^k$ . Addends (4) and (5) collect the production costs faced by company  $\hat{j}$ . These are the expenses due to raw materials employed respectively in clinker ( $p_i^{mk} \cdot m_n^k$ ) and in cement ( $p_i^{mc} \cdot m_n^c$ ) production, to the fuel ( $p_{g,i}^f \cdot f_{g,n,w}^k$ ) burnt in the kiln during the clinker production process, and to the electricity ( $p_i^e \cdot (e_n^k + e_n^c)$ ) used in the clinker and cement milling phases.

As far as the constraints are concerned, equalities (6) define the cement production balance of company  $\hat{j}$  in region  $i_l$ . In particular, each balance states that the quantity of cement produced by company  $\hat{j} \in J$  in region  $i_l \in Z_i$  has to be equal to the sum of the cement that  $\hat{j} \in J$  sells in the production region  $i_l \in Z_i$  and in the other regions  $h_r \in Z_h$  with  $h_r \neq i_l$ . The production of cement requires both clinker and raw materials. The two terms  $\rho_i \cdot q_{n,v}^c$  and  $(1 - \rho_i) \cdot q_{n,v}^c$  respectively indicate the amount of clinker demanded and raw materials used to produce cement. The mass balance constraint (8) computes the quantity of raw materials employed in cement production. Equalities (9) and (11) define the clinker demand per company  $\hat{j} \in J$  and region  $i_l \in Z_i$  respectively. More specifically, constraint (9) states a regional clinker balance. According to the level of cement production in region  $i_l \in Z_i$ , the corresponding clinker demand is fulfilled by the sum of local production and of clinker quantities imported from other regions. Equality (11) specifies that the sum of the

clinker bought ( $b_{\hat{j},i_l,j,h_r}^k$ ) by company  $\hat{j} \in J$  and of the clinker produced by the same company in region  $i_l \in Z_i$  and locally used ( $u_{\hat{j},i_l}^k$ ) is equal to the amount needed for cement manufacturing ( $\rho_i \cdot q_{n,v}^c$ ). Note that (9) is a shared constraint involving decision variables of all companies.

As stated in equality (8), once clinker is produced ( $q_{n,w}^k$ ), company  $\hat{j} \in J$  can either decide to locally use it ( $u_{\hat{j},i_l}^k$ ) or to sell ( $s_{\hat{j},i_l,j,h_r}^k$ ) it to other companies. Constraint (10) establishes a correspondence between the quantities of clinker exchanged among regions and companies. In other words, the quantity of clinker sold by company  $\hat{j} \in J$  to company  $j \in J, j \neq \hat{j}$  is equal to the quantity of clinker that company  $j \in J, j \neq \hat{j}$  buys from company  $\hat{j} \in J$ . This must hold for each pair of region considered. Conditions (12) and (13) respectively impose the capacity constraints on clinker production of plant  $n \in N_{\hat{j},i_l}$  which adopts technology  $w \in W_n$  and on cement production of plant  $n \in N_{\hat{j},i_l}$  with technology  $v \in V_n$ . Note that, on average, a kiln burns  $\sigma_i$  tons of raw material (limestone, chalk, marl and shale) to produce a tonne of clinker in a specific zone  $i$ .<sup>6</sup> This mass balance is defined by condition (14). Constraints (15) and (16) determine the quantity of electricity that is respectively used in the clinker and cement milling phases, while condition (17) defines the amount of fuel  $g$  burnt in plant  $n \in N_{\hat{j},i_l}$  for producing clinker. Finally, although not explicitly indicated among the conditions above, all variables included in this model are non-negative.

### 2.3 Clinker and cement producers' model under environmental policies

We analyze two possible policies *FA* and *BTA*, that can be applied in order to mitigate the carbon leakage phenomenon. The modeling of these policies implies a modification of the objective function of the producers' model presented in Section 2.2 and the introduction of an emission constraint that limits CO<sub>2</sub> emissions fully generated by clinker production. In fact, clinker production is responsible for the 100% direct CO<sub>2</sub> emissions of the whole cement production process. More specifically, when the *FA* applies, one has to replace the objective function  $\theta_{\hat{j}}$  with  $\varphi_{\hat{j}}$  that is given by

$$\varphi_{\hat{j}} = \theta_{\hat{j}} + FA_{\hat{j}}$$

where

$$FA_{\hat{j}} = p^{CO_2} \cdot \sum_{\substack{i \in I_{ETS}, i_l \in Z_i, \\ n \in N_{\hat{j},i_l}, w \in W_n}} (GA_{n,w} - \tau_{i,w} \cdot q_{n,w}^k) \quad (18)$$

The addend  $FA_{\hat{j}}$  defines the opportunity cost of emission allowances whose price is  $p^{CO_2}$ . Considering EU-ETS Directives' rules, we assume that CO<sub>2</sub> allowances are partially grandfathered. The grandfathered allowances ( $GA_{n,w}$ ) are thus used to cover the CO<sub>2</sub> emissions ( $\tau_{i,w} \cdot q_{n,w}^k$ ) generated for producing  $q_{n,w}^k$  according to an emission factor  $\tau_{i,w}$  that depends on zone  $i$  and technology  $w$ . We interpret the dual variable  $p^{CO_2}$  associated with the emission constraint (19), as the allowance price. Note that this variable becomes positive when (19) is strictly binding. This constraint states that the total CO<sub>2</sub> emissions generated by the regulated zones  $i \in I_{ETS}$  when producing clinker do not have to exceed the cap (*CAP*) imposed on cement sector in the

<sup>6</sup>See Cembureau (1999), European Commission (2010).

considered period.

$$CAP - \left( \sum_{\substack{j \in J, i \in IETS, i_l \in Z_i, \\ n \in N_{j,i_l}, w \in W_n}} \tau_{i,w} \cdot q_{n,w}^k \right) \geq 0 \quad (p^{CO_2}) \quad (19)$$

In the case of *BTA*, objective function  $\theta_{\hat{j}}$  is subject to similar changes. In particular,  $\theta_{\hat{j}}$  is substituted by  $\psi_{\hat{j}}$  that is defined as follows:

$$\psi_{\hat{j}} = \theta_{\hat{j}} + BTA_{\hat{j}}$$

where

$$BTA_{\hat{c}} = p^{CO_2} \cdot \left( \sum_{\substack{i \in IETS, i_l \in Z_i, \\ n \in N_{\hat{j},i_l}, w \in W_n}} (GA_{n,w} - \tau_{i,w} \cdot q_{n,w}^k) - \sum_{\substack{j \in J, j \neq \hat{j}, \\ i \in IETS, \\ h \in INETS, \\ i_l \in Z_i, h_r \in Z_h}} \delta_h \cdot b_{\hat{j},i_l,j,h_r}^k \right) \quad (20)$$

The term  $BTA_{\hat{j}}$  indicates that cement companies operating in EU-ETS zones have to cover the emission generated EU plants, but, in addition, they face a taxation for the quantity of clinker that they import from unregulated zones. This taxation concerns the amount of emission allowances that they have to give back for the CO<sub>2</sub> emitted ( $\delta_h \cdot b_{\hat{j},i_l,j,h_r}^k$ ) in unregulated zones for producing the imported clinker. The application of this policy also implies a modification of the emission constraint (19). In fact, it has to account not only for the emissions caused by kilns located in ETS zones ( $i \in IETS$ ), but also for the emissions generated by non-EU plants when producing clinker imported in EU countries. The sum of these emissions cannot exceed the total emission cap (*CAP*) defined for cement sector in the regulated zones. For this reason, the *BTA* policy implies the substitution of the emission constraint (19) with the following one:

$$CAP - \left( \sum_{\substack{j \in J, i \in IETS, \\ i_l \in Z_i, \\ n \in N_{j,i_l}, w \in W_n}} \tau_{i,w} \cdot q_{n,w}^k + \sum_{\substack{j, \bar{j} \in J, j \neq \bar{j}, \\ i \in IETS, h \in INETS, \\ i_l \in Z_i, h_r \in Z_h}} \delta_h \cdot b_{\hat{j},i_l,j,h_r}^k \right) \geq 0 \quad (p^{CO_2}) \quad (21)$$

The dual variable  $p^{CO_2}$  still indicates the endogenous allowance price.

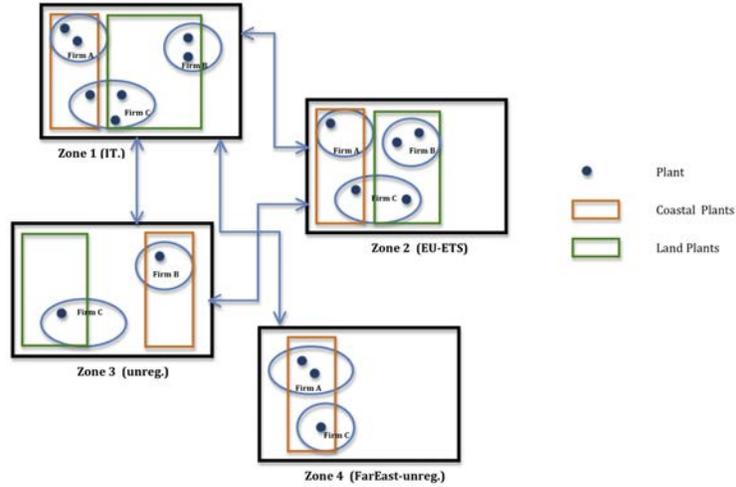


Figure 1: The case of four different zones and three firms

### 3 Database description

Our database gives an overall representation of the world cement sector with a particular focus on the Italian market, one of the most potentially exposed to the carbon leakage effect (see Reinaud, 2008). The analyzed international market is stylized in Figure 1. It is subdivided into four zones (Italy, Europe, Mediterranean area and Far East) that are further partitioned into coastal and inland regions. For each region, the cement market is built on the data related to the most representative countries: Europe collects data from Spain, Germany and France, Mediterranean area is based on Turkey and Egypt figures while Far East account for India and China<sup>7</sup>. Each company can have more than one plant in regulated and/or unregulated zones and can compete on the international market by selling and buying clinker and cement within the intra-regional and inter-regional areas (Figure 1 depicts the sample case of three firms).

We globally consider 80 cement plants<sup>8</sup>, both coastal and inland. Italian companies, namely Italcementi, Buzzi, Holcim, Cal.Me, Colacem and Cementir that represent the 70% of the Italian market are fully detailed in the database. We complete the Italian market with a fringe composed by the other small companies. Apart from Cal.Me, these are multinational firms operating at a worldwide level both in regulated and unregulated zones. Each plant is characterized by its clinker and cement capacity per technology. We consider three different clinker technologies (wet, semi-dry and dry) and a unique technology for producing cement. For each company and plant, clinker and cement capacity values have been estimated taking into account data provided by company's websites. Clinker to cement ratios in the different zones as well as data related to

<sup>7</sup>For the list of major cement producers Cembureau (2010).

<sup>8</sup>These include both the integrated plants that produce both clinker and cement and few cement mills that produce cement using clinker from other installations.

thermal energy consumption and emission factors are taken from the WBCSD database<sup>9</sup>.

Table 1: Raw Materials, fuels and electricity prices

<b>Input price/ Zone</b>	<b>Stones (€/t)</b>	<b>Coal (€/t)</b>	<b>Petcoke (€/t)</b>	<b>Altern. Fuels (€/t)</b>	<b>Clinker (€/t)</b>	<b>Electricity (€/MWh)</b>
<b>Italy</b>	3.75	87	69	6.5	54	71.32
<b>Europe</b>	3.13	80	65	6.5	58	56.53
<b>Mediterran.</b>	1.56	60	50	6.5	35	45.90
<b>Far East</b>	1.56	40	35	6.5	28	45.90

Table 1 reports data on raw material, fuels and electricity prices that have been estimated from Eurostat database<sup>10</sup> assuming year 2010 as reference. Data on conversion factors (such as electricity consumption) are also available on BREF 2010 (see European Commission, 2010). Table 2 reports data concerning fuel proportions.

Table 2: Fuel proportions in different zones

<b>Fuel prop./ Zone</b>	<b>Coal</b>	<b>Petcoke</b>	<b>Alternative Fuels</b>
<b>Italy</b>	82%	14%	4%
<b>Europe</b>	48%	34%	18%
<b>Mediterran.</b>	20%	79%	1%
<b>Far East</b>	6%	94%	0%

Zonal cement demand is formulated with an inverse linear demand function; demand parameters (zonal reference price and consumption) are estimated using 2010 data provided by Eurostat<sup>11</sup>. On the lines of the relevant literature (see Cook, 2011a; Demailly and Quirion, 2006; Droege, 2012) we set as base case a demand elasticity equal to 0.2 which indicates that cement demand is highly inelastic to price. We also analyze a different market elasticity level (0.8) which indicates a higher sensitive demand to price in order to evaluate the different impact of environmental policies when cement market is more competitive. Clinker zonal demand is determined as a function of the zonal cement production (see Section 2) while clinker prices are exogenous and computed on the basis of Eurostat database. Transportation costs are estimated on the basis of data provided by Boston Consulting Group (2008b). Cement transportation costs are around 20% higher than those of clinker and their amount varies according to the type of transport used and the geographical distribution of plants. This makes the cement market, especially for inland plants, quite regional. This is not the case for the coastal plants that can be reached also by sea and thus are more open to international markets (see Droege, 2012). Finally, since we do not account for investment policies, we assume that, for each plant, the investment costs have been fully amortized. We leave this kind of analysis for future research.

<sup>9</sup>This database is available online at <http://www.wbcscement.org/GNR-2010/index.html>

<sup>10</sup>Source: [http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search\\_database](http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database).

<sup>11</sup>Source: [http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search\\_database](http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database)

## 4 Results

As indicated above, we analyze the cement market behavior by varying environmental policy measures. In particular, we analyze the cement market under three different CO<sub>2</sub> emission policies: absence of EU-ETS (*No Cap*), *FA* and *BTA* measures. For both *BTA* and *FA*, we assume two possible emission caps (*Cap 80* and *Cap 50*) on CO<sub>2</sub> emissions for regulated zones. We thus globally consider five ETS scenarios (*No Cap*, *FA Cap 80*, *FA Cap 50*, *BTA Cap 80* and *BTA Cap 50*).

We measure the carbon leakage rate on both clinker and cement production and we define it as the ratio between the increase of EU regulated countries' clinker/cement imports from non-EU areas and the reduction in coastal and inland clinker/cement production in EU regulated countries. The increase in clinker/cement imports in EU regulated countries is computed as the difference between their amount before and after the application of the environmental policy. Similarly, the decrease in clinker production in EU regulated countries results from the comparison between their levels before and after the environmental policy. In other words, the carbon leakage rate is computed using the following ratio:

$$\frac{(\text{NO Cap} - \text{Cap}) \text{ imports}}{(\text{NO Cap} - \text{Cap}) \text{ production}}$$

### 4.1 Results on the Italian cement market

Figures 2 and 3 report the main results concerning the Italian cement market under the assumption of 0.2 elasticity for cement demand. Figure 2 illustrates clinker consumption under the different scenarios for the coastal and inland regions. Trends differ on the basis of the geographical locations of the plants.

In the coastal consumption, clinker imports from unregulated countries, such as Far-East, play an important role, especially under the *FA* policy. In *No Cap*, only a small proportion of the Italian clinker consumption is covered by Far-Eastern clinker. This quota raises to 100% when the *FA* policy applies, independently of the CO<sub>2</sub> cap imposed. This happens because coastal plants find more convenient to import clinker from unregulated countries than buying CO<sub>2</sub> allowances. With this strategy, they can also gain by selling the grandfathered allowances. In addition, Far-East countries can export huge amounts of clinker and cement because their global production capacity overcomes the internal demand for these two goods. Under the *BTA* policy, producers' strategies vary according to the CO<sub>2</sub> cap. In the *BTA Cap 80* case, clinker demand remains almost unchanged compared to *No Cap* and imports from Far-East are much lower compared to those in the *No Cap* and the *FA* scenarios. This is due to the nature of this policy that imposes a taxation on clinker imports. This phenomenon is enhanced in the *BTA Cap 50* case, where there are no imports from unregulated countries and a strong contraction of clinker internal consumption (-55%) with respect to the *No Cap* scenario. This significant clinker consumption drop is compensated by cement imports from unregulated countries, as one can see from Figure 3.

In the *BTA Cap 50* case, cement imports from Far-East and Mediterranean areas play an important role for coastal regions: these cover the 43% of the total coastal cement demand. This means that the *BTA* policy has

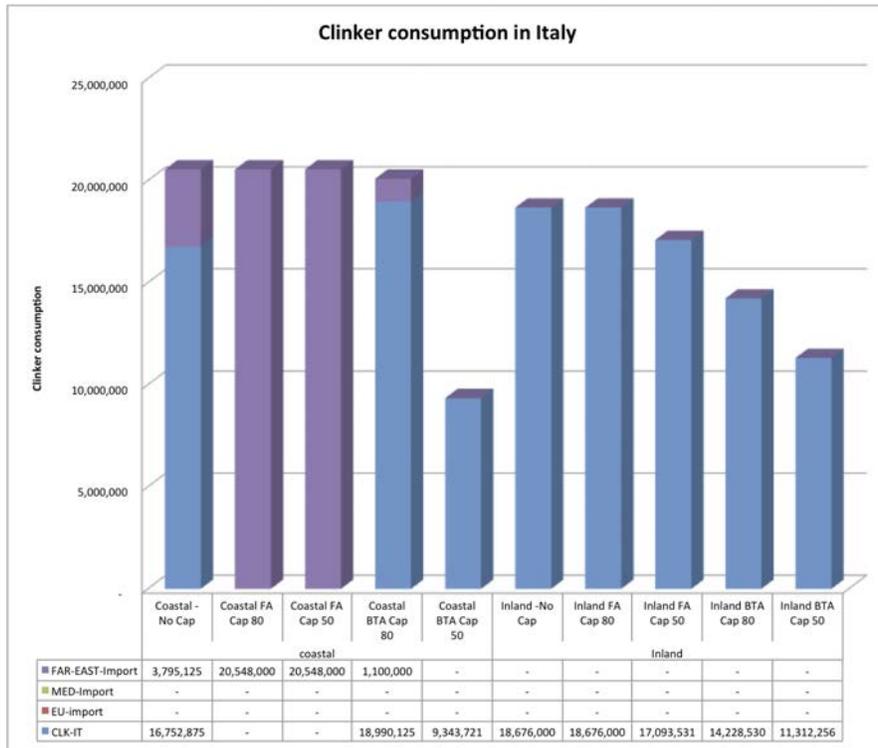
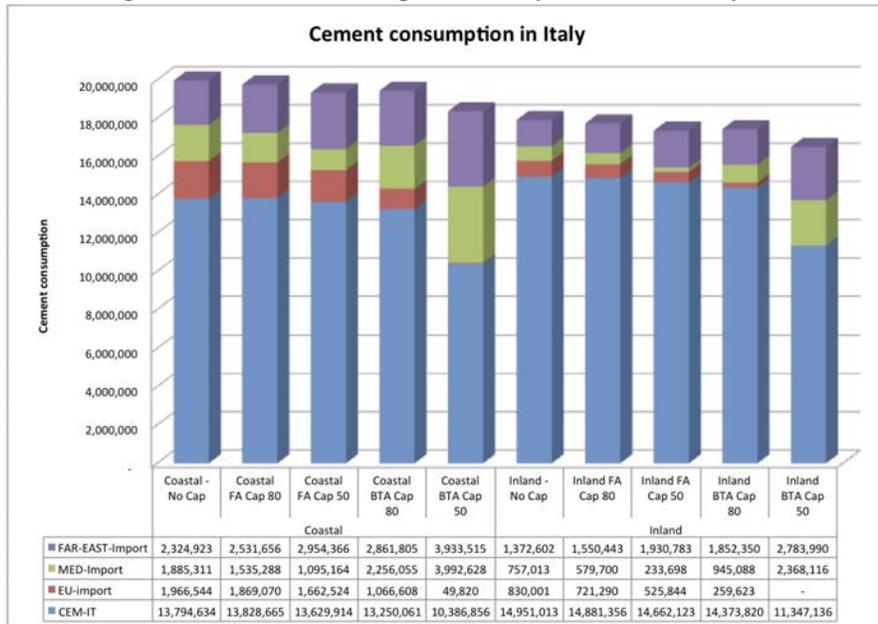


Figure 2: Clinker consumption in Italy in ton (elasticity 0.2)

Figure 3: Cement consumption in Italy in ton (elasticity 0.2)



different effects on clinker and cement exchanges. Since clinker coming from unregulated countries is taxed, producers prefer to directly import cement on which no environmental costs are imposed. This is a way to bypass the *BTA* regulation. On the other side, when considering the two *FA* policy scenarios, one can see that the total cement consumption slightly decreases in presence of regulation. This reduction is proportional to the reference caps. Moreover, in the *No Cap* and in both *FA* policy cases imports from Far East and Mediterranean areas cover the 21% of the total cement demand. Their single contribution varies accordingly to the case analyzed. This particularly holds for the cement imports from Far-East which progressively increase as far as the *FA* policy becomes more restrictive. Finally, in all scenarios, a part of the demand is also covered by European cement production, but it has a decreasing trend. In inland regions, one can observe different behaviors compared to those in coastal zones especially in clinker consumption (see Figure 2). Because of the high transportation costs, cement companies do not import clinker and the consumption is based only on Italian production in all cases. Moreover, consumption levels are affected both by the environmental policies and by the choices adopted for covering the clinker coastal demand in the regulated areas. With the *FA* regulation, companies operating in the Italian and European coastal areas import clinker. This *FA* strategy not only leads to lower CO<sub>2</sub> prices (see Table 3), but also allows to keep the clinker production in the inland regions almost unchanged compared to the *No Cap* level. In fact, clinker demand is not affected in the *FA Cap 80* case and only reduces by 8% in the *FA Cap 50* scenario. The situation changes with the *BTA* measure. Since clinker imports from unregulated countries are extremely costly for companies operating in Italy and in Europe, clinker total<sup>12</sup> consumption is mainly based on local production that is implicitly limited by the ceiling imposed on carbon emissions. As backside effects, the CO<sub>2</sub> prices are more than doubled compared to those of the *FA* scenarios (see Table 3) and clinker consumption falls especially when the cap is more restrictive. This is particularly evident both in the coastal and inland *BTA Cap 50* cases in Figure 2. As already observed for the coastal scenarios, the reduction of the clinker consumption in the *BTA* is mainly accompanied by an increase of cement imports from unregulated countries. The cement imports from unregulated countries cover the 16% and the 31% of the cement Italian consumption respectively in the *BTA Cap 80* and *BTA Cap 50* cases. There are also some cement imports from Europe, but in very limited quantities. On the contrary, the cement consumption in the *FA* remains almost in line with that of the *No Cap* case (see Figure 3) and the trend of cement imports is identical to that of the coastal areas. These trends of clinker consumption are confirmed when we analyze a more elastic market by assuming a 0.8 elasticity for cement demand as illustrated by results reported in Appendix A (see Figures 8 and 9).

## 4.2 Results on the European cement market

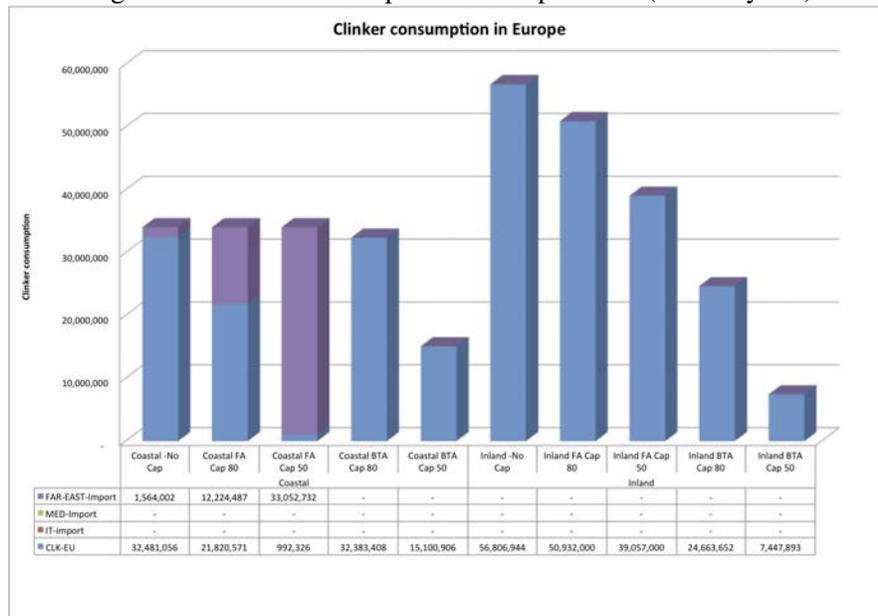
Figures 4 and 5 respectively report the clinker and the cement consumption in Europe under the assumption of 0.2 cement demand's elasticity. The clinker demand evolution in the different coastal and inland scenarios in Figure 4 is similar to that illustrated in Figure 2 for the Italian market. Regarding the coastal regions, the

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<sup>12</sup>Inland plus coastal demand.

consumption levels in the *No Cap* and in the two *FA* cases is identical, but when the *FA* cases apply the local clinker production is progressively replaced with imports from the Far-East. This allows companies to avoid the carbon costs determined by the EU-ETS. However, compared to the Italian market, the clinker imported from unregulated countries covers a lower amount of the demand.

Figure 4: Clinker consumption in Europe in ton (elasticity 0.2)

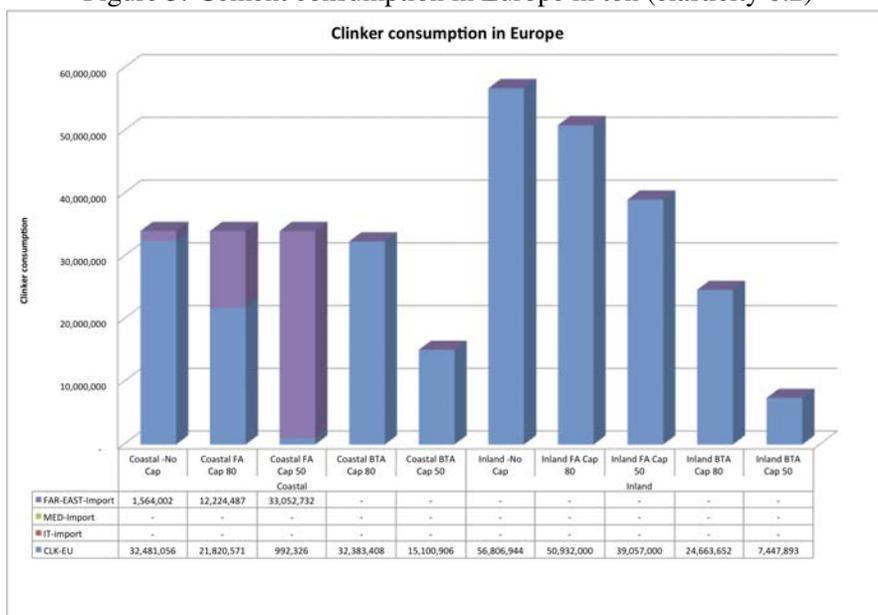


As for the Italian market, clinker consumption in Europe more than halves in the *BTA* scenarios. The reasons that induce companies to cut their clinker consumption and not to import are the same of those described in Section 4.1. On the other side, clinker demand in the inland regions is only supplied by local production because the high transportation costs do not make imports convenient. Environmental policies cause a decrease of the total consumption that becomes drastic in the *BTA* cases. Again, this is a direct effect of the environmental costs that companies try to compensate by importing a significant amount of cement. As shown in Figure 5, the provenience of these imports is particular significant. In fact, imports from Italy, especially from coastal regions, satisfy on average, the 21% of the coastal demand and the 13% of the inland demand<sup>13</sup>. The relatively low transportation costs from Italy induce Europe to consume Italian cement. However, the total cement imports from unregulated countries overcome those from Italy and among these the amount of cement coming from Mediterranean area is comparable or even higher than that from Far-East. This particularly holds true in the extreme *BTA Cap 50* case.

Under the assumption of a 0.8 cement demand elasticity, clinker consumption in the different cases evolves

<sup>13</sup>Note that from these average computations the coastal and the inland *BTA cap 50* scenarios are excluded because, in these cases, Italian cement covers respectively the 10% and the 2% of the total European demand. Thus their contribution is much lower than in the other scenarios of the same group.

Figure 5: Cement consumption in Europe in ton (elasticity 0.2)



as in the 0.2 scenarios, even though the demand drops in inland regions due to environmental regulations are less drastic (see Figure 10 in Appendix A). Cement consumption is similar to that of the Italian market, except for the European imports that are replaced with those from Italy (compare Figures 9 and 11 in Appendix A).

### 4.3 Carbon leakage analysis

The results presented in Sections 4.1 and 4.2 show that the clinker and the cement exchanges between regulated and unregulated areas depend on the environmental policy implemented. The *FA* policy induces companies to import clinker from unregulated countries without significantly changing their cement trade. The implications on international trade due to the *BTA* measure are exactly the opposite. These effects can be translated in terms of carbon leakage rates that we report in Table 3 below.

Table 3: CO<sub>2</sub> allowance prices, cement prices and clinker and cement carbon leakage (cement demand elasticity 0.2)

	CO <sub>2</sub> price (€/ton)	Carbon leakage Clinker		Carbon Leakage Cement		Cement prices (€/ton)			
		IT	EU	IT	EU	IT		EU	
						Coastal	Inland	Coastal	Inland
<b>No Cap</b>	-	-	-	-	-	105.22	121.64	115.09	134.28
<b>FA Cap 80</b>	32.49	100%	64%	n.l.	n.l.	108.66	124.90	118.55	137.74
<b>FA Cap 50</b>	53.64	91%	64%	n.l.	n.l.	115.70	131.87	125.87	144.93
<b>BTA Cap 80</b>	68.74	n.l.	n.l.	26%	8%	114.16	130.44	124.01	143.01
<b>BTA Cap 50</b>	117.76	n.l.	n.l.	29%	20%	132.02	147.52	141.30	160.34

Because of its geographical characteristic, Italy is more exposed to carbon leakage than Europe<sup>14</sup>. As expected, the application of the *FA* policy causes a carbon leakage phenomenon on clinker. Considering the Italian market, the clinker carbon leakage rates are of 100% and 91% respectively in the *FA Cap 80* and in the *FA Cap 50* cases. The lower carbon leakage rate in *FA Cap 50* depends on how we define this index. While the variation between the clinker imported in the *No Cap* and in the two *FA* scenarios is the same<sup>15</sup>, the corresponding variations in clinker production is higher in *Cap 50* than in *Cap 80*<sup>16</sup>. For this reason, the ratio between variations in clinker imports and in clinker production leads to a lower carbon leakage level in the *FA Cap 50* case. The European clinker carbon leakage rates amount to 64% both in the *FA Cap 80* and *FA Cap 50* scenarios. In fact, the higher variation of clinker imports in the *FA Cap 50* is compensated by a more significant reduction in clinker production compared to the level in the *No Cap* case. This production drop is influenced by the higher CO<sub>2</sub> price. On the other side, there is no carbon leakage on cement denoted as n.l.” (no leakage) in Table 3. With the application of a *BTA* policy, carbon leakage effect appears on cement. The taxation imposed by this policy on clinker imported from unregulated countries induces companies operating Italian and European plants to buy cement from Far-East and Mediterranean areas in order to cover internal demand. Again, this phenomenon is more evident in Italy than in Europe, even though it remains more limited compared to what happens in the clinker market. Moreover, the restrictive cap of the *Cap 50* case forces Italian and European producers to increase the use of unregulated cement to satisfy the internal demand. With the *BTA* policy, the amount of clinker locally produced significantly decreases because of the carbon price. In addition, the CO<sub>2</sub> tax on clinker from unregulated countries forces industries not to purchase it from Far-East and Mediterranean area. For these reasons, there is no carbon leakage on clinker in the *BTA* cases. Finally, the carbon leakage rates under the assumption of 0.8 elasticity for cement demand have trends that are similar to those presented in this Section (compare Tables 3 and 4 in Appendix A), even though the incremented flexibility induces companies to exercise carbon leakage also on cement in the *FA* cases.

#### 4.4 Profit analysis

Figure 6 compares the profits under different policy and elasticity scenarios. Since under the 0.8 elasticity assumption the market is more flexible, cement and CO<sub>2</sub> prices are lower than under the 0.2 elasticity hypothesis. For this reason, profits are generally higher in the 0.2 scenarios compared to those of the corresponding 0.8 cases, even though their trends are globally similar.

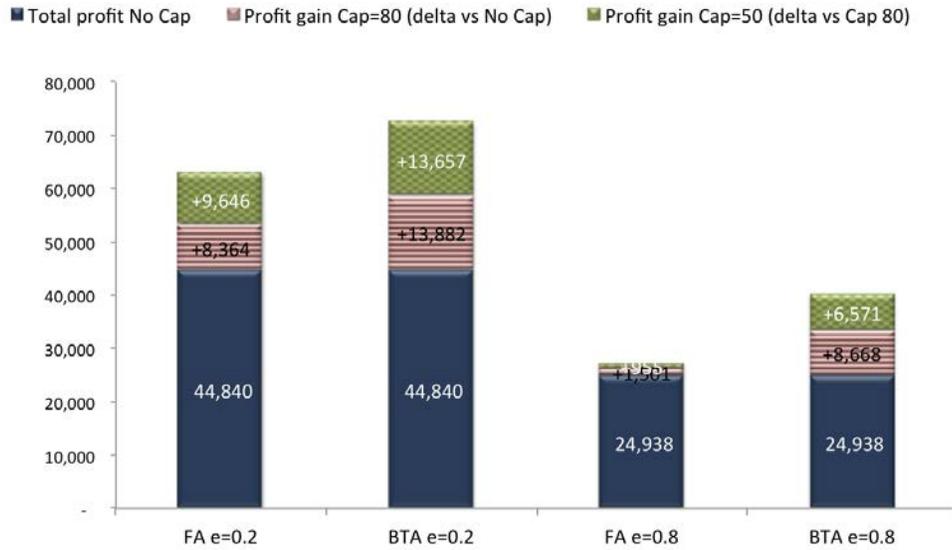
The application of both the *BTA* and the *FA* policies raises cement profits compared to the situation without any environmental regulations (blue part of the bar in Figure 6). The profit increment is determined both by cement prices, that are higher with environmental regulations, and by the CO<sub>2</sub> prices. These increases are proportional to the values assumed by these two groups of prices (see Tables 3 and 4) and explain the results

<sup>14</sup>Recall that in our simulations, the European market accounts for Spain, Germany and France.

<sup>15</sup>There are no clinker imports in the inland zone and in both *FA* coastal cases clinker imports cover the 100% of the demand.

<sup>16</sup>With a more restrictive cap, cement producers reduce their clinker production. This choice is influenced by the increase of the CO<sub>2</sub> price compared to its level in the *Cap 80* scenario (see Table 3).

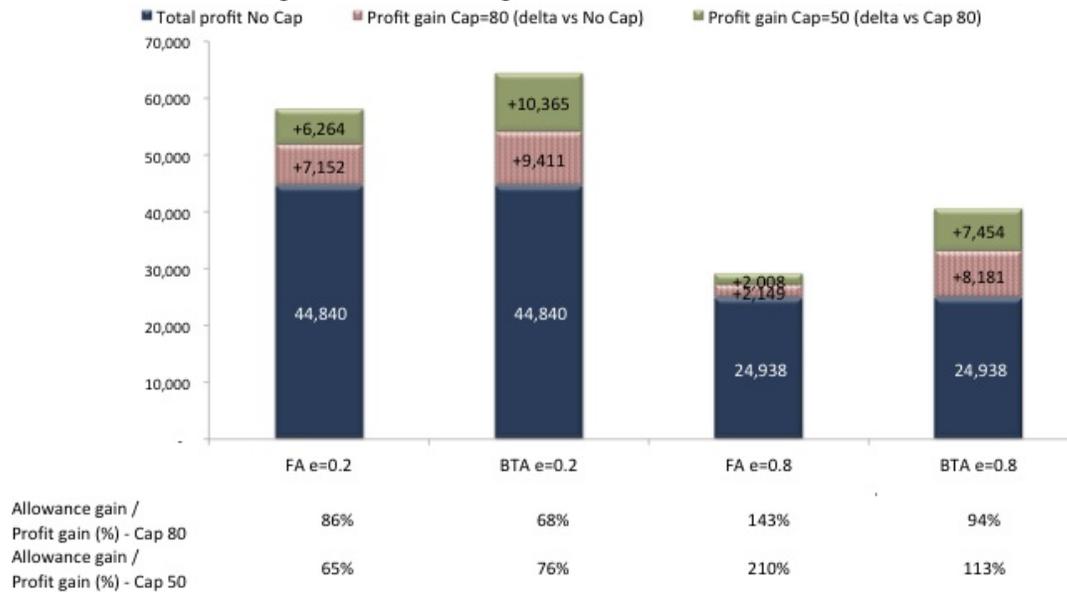
Figure 6: Profit analysis



shown in Figure 6. Note that CO<sub>2</sub> prices influence profit because cement producers can sell the excess of their grandfathered allowances on the emission market and therefore increment their revenues<sup>17</sup>. This especially holds true when companies exercise carbon leakage on clinker whose production causes CO<sub>2</sub> gasses. Figure 7 provides a measure in percentage of the importance assumed by allowance gain in companies' profits. This is computed as a proportion of the single profit increases in the different scenarios and it varies according to the cases analyzed. Under the 0.2 elasticity assumption, the allowance gain justifies the profit increases for percentages ranging between the 65% and the 86%. When the market is more elastic (0.8), these proportions are extremely high and in the *FA Cap 50* case it reaches the value of 210%. This happens because the allowance gain is used to offset the other operative costs.

<sup>17</sup>Recall that the emission market includes many energy intensive industries other than cement companies.

Figure 7: Allowance gain in the different scenarios



## 5 Conclusions

This paper proposes a spatial equilibrium model for analyzing the carbon leakage effect on the European and Italian cement market under EU-ETS regulation and two possible measures for mitigating it. Our analysis shows that the Italian and the European cement markets are exposed to carbon leakage and this exposure is higher for coastal plants especially when the regulation is more stringent. By comparing Italian and European markets, Italy is the most exposed and this depends on the location of its plants that are mainly installed in coastal areas. In this respect, the results of our model are broadly consistent with the literature. Our results point out that the two environmental measures envisaged to mitigate this phenomenon may be not completely effective. Under the *FA* scenarios, companies import clinker from unregulated countries in order to reduce their emission levels and gain from selling grandfathered allowances. With the application of the *BTA* measure, cement producers significantly reduce the consumption of clinker produced in Italy and in Europe and directly import cement from unregulated areas. In other words, they simply adjust their production and international trade of cement and clinker in order to limit their carbon costs. As a consequence, CO<sub>2</sub> emissions at international level may not be significantly reduced.

## Appendix A: Additional results

In this appendix, we provide additional results of our analysis. These are related to the simulations with a 0.8 cement demand's elasticity.

Figure 8: Clinker consumption in Italy in ton (elasticity 0.8)

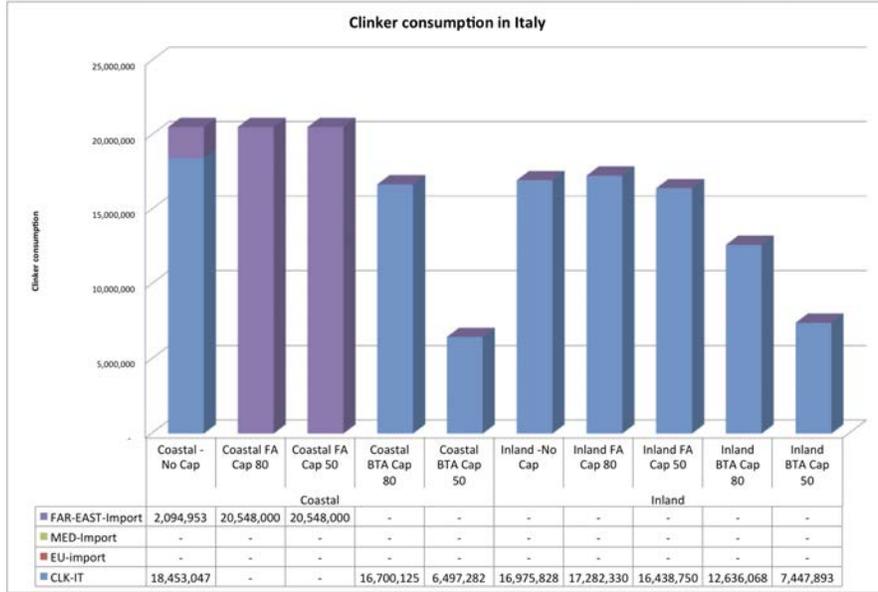


Table 4: CO<sub>2</sub> allowance prices, cement prices and clinker and cement carbon leakage (cement demand elasticity 0.8)

	CO <sub>2</sub> price (€/ton)	Carbon leakage		Carbon Leakage		Cement prices (€/ton)			
		Clinker	Cement	Clinker	Cement	Coastal	Inland	Coastal	Inland
<b>No Cap</b>	-	-	-	-	-	65.29	77.62	75.09	88.21
<b>FA Cap 80</b>	9.76	102%	48%	n.l.	10%	66.45	78.61	76.77	90.26
<b>FA Cap 50</b>	16.62	97%	10%	68%	14%	68.39	80.74	79.30	93.26
<b>BTA Cap 80</b>	45.43	n.l.	n.l.	34%	41%	76.85	90.15	86.88	101.55
<b>BTA Cap 50</b>	78.11	n.l.	n.l.	52%	54%	90.99	106.51	95.27	110.70

Figure 9: Cement consumption in Italy in ton (elasticity 0.8)

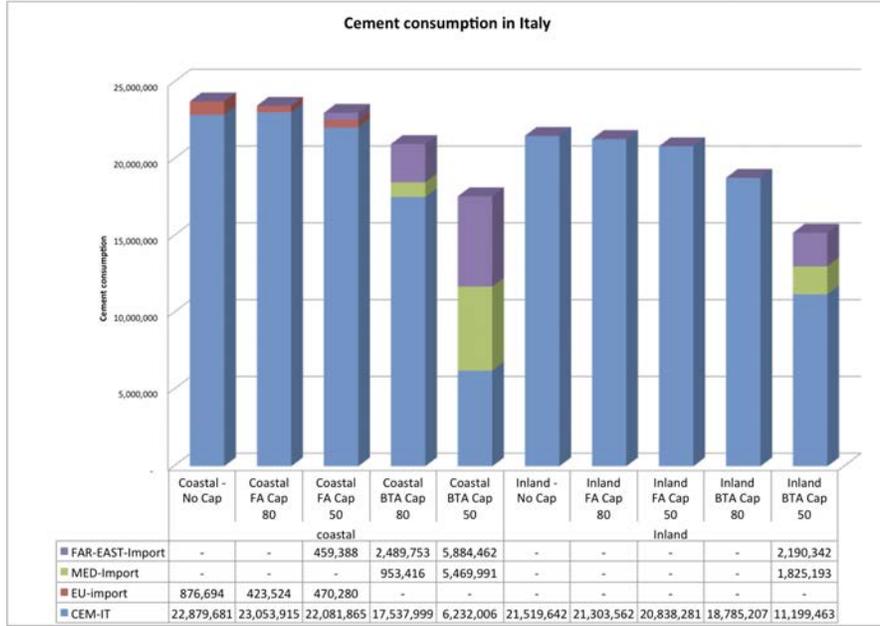


Figure 10: Clinker consumption in Europe in ton (elasticity 0.8)

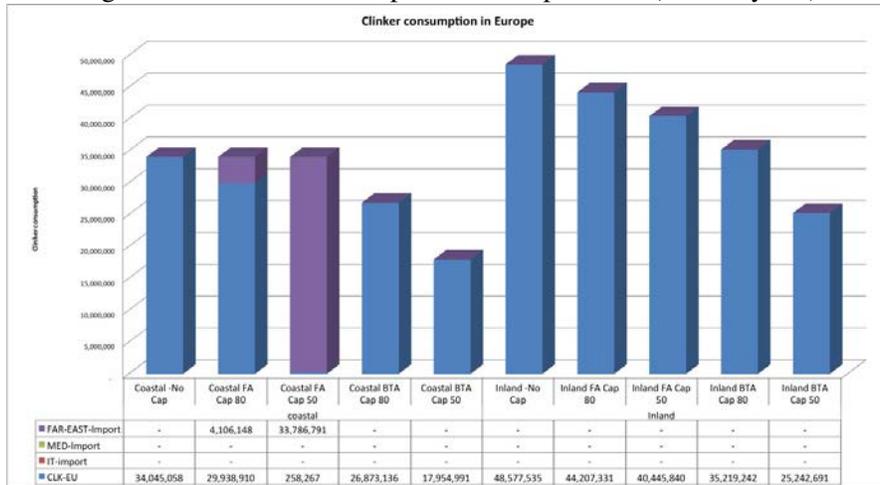
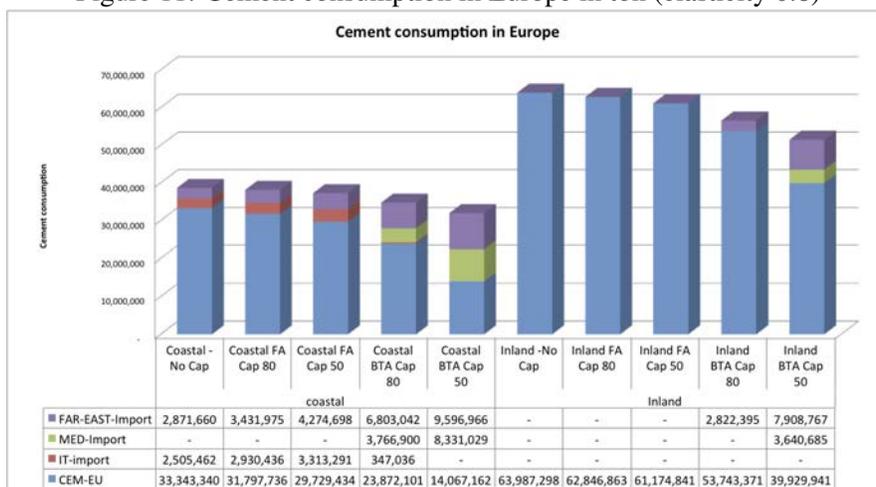


Figure 11: Cement consumption in Europe in ton (elasticity 0.8)



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