CECILIA 2050

OPTIMAL EU CLIMATE POLICY

**Choosing Efficient Combinations of Policy Instruments for Low-carbon development and Innovation to Achieve Europe's 2050 climate targets**

# Understanding the impacts and limitations of the current instrument mix in detail: industrial sector

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SEVENTH FRAMEWORK PROGRAMME

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| | |
|---|---|
| p.a. | Per annum |
| GHG | Greenhouse gas |
| WP | Work Package |
| GNR | Getting the Number Rights database |
| EUTL | European Union Transaction Log |
| UNFCCC | United Nations Framework Convention on Climate Change |
| IEA | International energy Agency |
| WBCSD | World Business council for Sustainable Development |

# 1 Executive summary

We assess whether the EU ETS has reduced $CO_2$ emissions in the cement sector, and whether it has generated carbon leakage in the cement and steel sectors. A first conclusion, based on the examination of the best available data, is that abatement from the EU ETS in the cement sector, if any, has been very limited (maybe 2%). Analysing separately the drivers of emissions, we conclude that:

- the EU ETS has not reduced the energy intensity of clinker production;
- there is no clear impact on the carbon intensity of the fuel mix;
- the EU ETS seems to have reduced the clinker ratio by approximately 2 percentage points, compared to the historical trend.

A second conclusion is that the EU ETS has not generated carbon leakage, at least in the short run ('operational leakage') in the cement and steel sectors. Our analysis on this point is based on various econometric methods whose results converge, which provides confidence on the results robustness.

# 2 Introduction

In the manufacturing industry, the main existing policy tool to reduce GHG emissions is the EU ETS. Admittedly, at least in some member states, manufacturing industry is covered by other policy instruments: carbon/energy taxes, regulatory measures or subsidies. Yet most member States with carbon/energy taxes have exempted heavy industry and/or emission sources covered by the ETS (as in Sweden and in Ireland, and as is currently planned in France), while regulatory measures like those implemented in accordance to the IPPC (Integrated Pollution Prevention and Control) directive mostly target other pollutants and risks, rather than GHG. Finally, subsidies for GHG abatement in the manufacturing industry, which are constrained by state aid rules, represent a much more limited implicit $CO_2$ price than the EU ETS.

Consequently, this deliverable focusses on the EU ETS, and in particular on the two main manufacturing sectors covered by the scheme (measured by emissions, Kettner et al. 2013): cement and steel. It contributes to the growing literature assessing the EU ETS *ex post* (cf. Martin et al., 2012a, and references therein).

More specifically it addresses two questions: did the EU ETS reduce $CO_2$ emissions in the cement sector? Did it generate competitiveness losses and carbon leakage through production offshoring in the cement and steel sectors? The first question (section 3) deals with the effectiveness of the ETS in these sectors while the second (section 4) is about potential unintended consequences of the system. Section 5 concludes.

# 3 Did the EU ETS reduce $CO_2$ emissions in the cement sector?

## 3.1 Introduction

Although a significant number of papers have assessed the effectiveness of the EU ETS, most existing evaluations either remain at a very aggregate level or focus on the power sector: there are very few estimates of the policy's specific effect on manufacturing industry (Martin et al., 2012a).

Ellerman and Feilhauer (2008) provide estimates of abatement due to the ETS in the German manufacturing industry in phase I (about 6% of emissions in their calculation), but simply by calculating the difference between the estimated aggregate abatement and the estimated abatement in the power sector. Consequently, they acknowledge that this approach cannot provide precise evidence.

A second study by Egenhofer et al. (2011) looks at the evolution of emission intensity (i.e. emissions/gross value added) in the manufacturing sectors covered by the ETS in 2008 and 2009 and finds almost no evolution. More precisely the improvement in $CO_2$ intensity was lower in 2008 than in the preceding years (-0.4% vs. -2.3%) while it was higher in 2009 (-5.1% vs. -2.3%), implying an abatement of less than 0.5% per annum over these two years, on average. Notice that this study does not account for the changes in energy prices during the period. Moreover it only considers the gross value added of manufacturing industry as a whole while its sub-components, whose $CO_2$ intensity widely differs, have had different trends during the period considered.

Kettner et al. (2013) analyse two manufacturing industry sectors (cement and lime; pulp and paper) up to 2010. Although emissions went down in both sectors, the main explanation is the economic crisis which reduced demand and thus output. In addition, in pulp and paper, the authors conclude that emissions have been reduced through a decrease in carbon intensity, itself driven by fuel switch towards biomass and natural gas. In cement and lime, they argue that the decrease in carbon intensity was driven by an increase in clinker imports because, according to UNFCCC data, clinker emission intensity has been almost constant over the period.

The other relevant study is Abrell et al. (2011) who estimate, at the firm level, reductions in $CO_2$ emissions around the transition from the first to the second phase. They assess EU ETS firms' emissions reduction in 2005-2006 compared to 2007-2008. The results indicate that emission reductions between 2007 and 2008 were 3.6% larger than between 2005 and 2006. According to the authors, the controls included in their estimation implied that this shift was likely to be due to the change from Phase I to Phase II, and that it was not implied by a proportionate decrease in production: emissions reductions were not caused only by economic conditions or reductions in the economic activity of firms. However, the yearly average spot $CO_2$ price increased significantly from 2007 to 2008, while it decreased from 2005 to 2006, which also might explain the results. Taking a closer look at some sectors, the authors conclude that basic metals and non-metallic minerals significantly increased their reduction efforts between 2005-06 and 2007-08. More precisely, when controlling for companies' turnover, number of employees, sector and home country, non-metallic minerals firms increased their abatement by 8.7% and basic metals firms by 9.5%.

Hence, this review of the (limited) existing literature brings contradictory results. Abrell et al. (2011) find a significant reduction in carbon intensity for basic metals (whose emissions occur mostly in the steel sector) and non-metallic minerals (whose emissions occur mostly in the cement sector) between 2007 and 2008 compared to 2005-2006. Yet Kettner et al. (2013) find very limited reduction in carbon intensity in the cement and lime sector, and attribute most of it to an increase in clinker imports – which implies carbon leakage. Moreover Egenhofer et al. (2011) find almost no decrease in manufacturing industry's carbon intensity in 2008, which seems to contradict Abrell et al. (2011) results.

Explaining these contradictions is difficult since the studies use different datasets for emissions (CITL or UNFCCC) and for economic activity. This calls for a careful analysis of the emissions and production data. Moreover, longer time series, and in some cases more accurate data sources, are available than those used in these studies, especially in the cement sector. Hence, in the following, we present an original study based on longer time series (up to 2011) and as we shall argue a more accurate database, but in the conclusion of this third section we come back to the results of the above-mentioned studies.

## 3.2 Cement production process and potential for abatement

In the cement sector, $CO_2$ emissions occur during the production of clinker, an intermediate product which constitutes about 75% of cement in mass, and which is only used to produce cement. Clinker is produced by heating limestone in a rotating kiln. In the oldest kilns, some of which are still in operation, limestone is introduced as slurry ('wet production route') while in more recent ones, it is introduced as a powder ('dry production route') which consumes less energy since less water has to be evaporated. In addition, in recent kilns, part of the waste heat is recovered (pre-heating and pre-calcining of raw material). Around 40% of $CO_2$ emissions are due to the burning of fossil fuel. Any fuel can be used, so operators choose the cheapest ones, mostly pulverised coal or petroleum coke (petcoke) in Europe, with also some 'alternative fuels', i.e. various types of waste or biomass. The remaining 60% are process emissions, i.e. due to the chemical reaction itself: the transformation of limestone into clinker generates around 0.53 t $CO_2$/t clinker (a little more for clinker used in some special products like white cement).

Clinker is then grinded and mixed with other materials, mostly limestone, gypsum, puzzolana, blast furnace slag (a by-product of steelmaking), and fly ash from power plants. The share of these other components, the production of which does not emit much $CO_2$[1], currently reaches 25% in average in Europe and 32% in Brazil (WBCSD, 2013). Traditional Portland cement is made of 95% of clinker while ‘blended’ cement includes a higher rate of other components.

Alternative cements, produced without clinker, exist, and some of them have been available for more than a century. However, their production is extremely limited compared to Portland or blended cements. Whether their development is mostly hindered by inertia in business practice and specifications for building materials, or by more fundamental reasons like unproven durability or higher cost, remains an open question. Juenger et al. (2011) provide an up-to-date synthesis of the advances in alternative cements.

Cement – whether Portland, blended or alternative – is then mixed with other mineral elements to form concrete, a building material. This quick overview of the production process allows identifying the various options available to reduce $CO_2$ emissions from cement production (cf. the green arrows in Figure 3-1, borrowed from Neuhoff, 2009).

1. Increase $CO_2$ efficiency of clinker production, i.e. reduce $CO_2$ per tonne of clinker. Progress on this point can be due to:

   1.1. An increase in the energy efficiency of clinker production, by switching to modern kilns (dry production route with pre-heater and pre-calciner) away from old ones (especially the less efficient wet, semi-wet or semi-dry kilns) or by a more efficient operation of the kilns. For example, energy efficiency decreases if the kiln production is lower than its nominal capacity.

   1.2. A reduction of the carbon content of fuels. In Europe, this comes mostly from the use of various forms of biomass waste. Note however that burning more waste may reduce the energy efficiency.

   1.3. $CO_2$ capture and storage, which is still at a development stage.

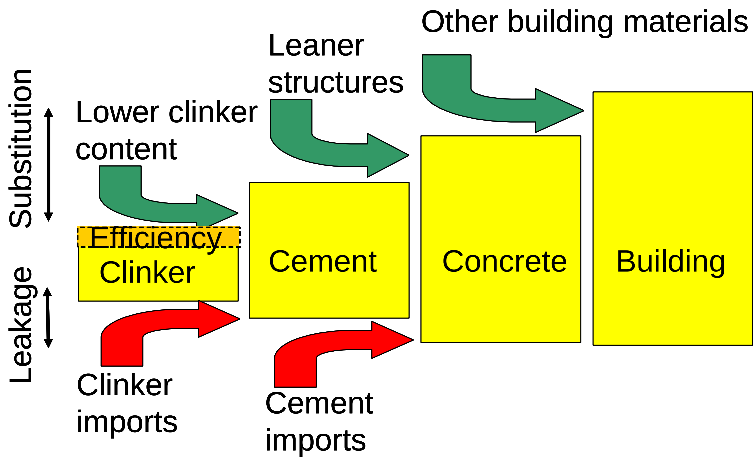
2. Lower clinker content, i.e. increase the share of other components than clinker in cement.

3. A reduction in the amount of cement used, through leaner structures or the use of other, less $CO_2$-intensive, building materials, mainly wood.

The challenge of a non-global climate policy, in this sector, is to induce all these substitutions without increasing clinker or cement imports, i.e. without carbon leakage (red arrows in Figure 3-1).

[1] Making the assumption that the output of power plants and steel plants, which produce respectively fly ash and slag, is not influenced by the use of these by-products (or wastes) in cement production. This assumption is reasonable since the value of these by-products (or wastes) is extremely low compared to that of the main products.

**Figure 3-1 Potentials for $CO_2$ abatement and leakage in the cement value chain**




Source: Neuhoff (2009)

The leakage issue will be dealt with in section 4. Before that, in this third section, we discuss how these drivers of emissions have evolved in the EU before and after the start of the EU ETS, in order to shed some light on the ETS efficiency.

## 3.3 Data sources

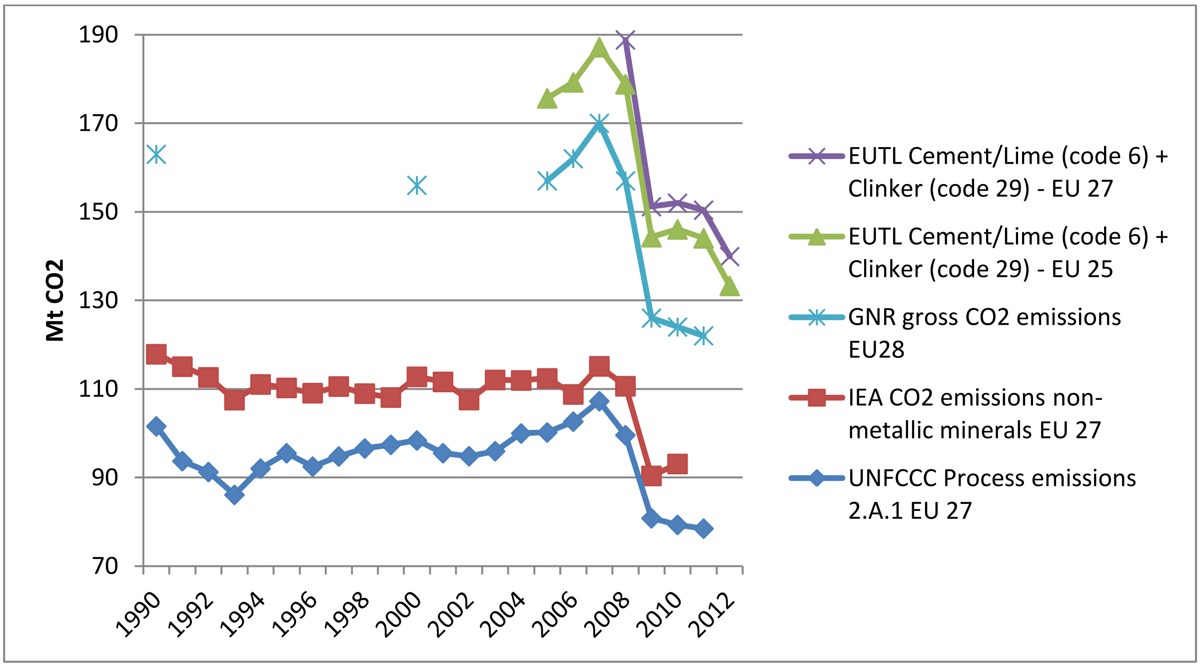
As shown in Figure 3-2, different data sources for cement $CO_2$ emissions exist and bring very different results. From the top to the bottom of the figure, we find:

- The European Union Transaction Log (EUTL, previously known as the CITL), which brings together emission data collected for compliance to the EU ETS. It may seem at first sight a natural candidate, but suffers from two serious drawbacks. First, it starts only in 2005, thus preventing to analyse the difference in emission trends before and after the start of the EU ETS. Second, it gathers emissions from cement and lime, which, as we shall see, seem to have had different emission dynamics in recent years. On the Figure, we plot both data for EU 27 (which are available only since 2008) and for EU 25, which exist since 2005.
- The GNR (Getting the Number Rights) database, provided by the WBCSD (2013). We will use this source because it does not suffer from the two above-mentioned drawbacks: years 1990 and 2000 are available (although data are less reliable for 1990) and it only covers emissions from clinker production. Moreover it provides, in a consistent framework, other data related to production and technical choices, some of which we will use in the next section. The only drawbacks are, first, that 2012 data are not available yet and, second, that a change in the reporting method occurred for $CO_2$ emissions from waste; we will discuss this issue in the next section.
- The IEA $CO_2$ emissions from non-metallic minerals. This source suffers from two critical drawbacks: it does not cover process emissions and it covers many other sectors than cement (lime, as the EUTL, but also bricks, tiles, ceramics…). Hence we will not use it in this report.

- The UNFCCC gathers national inventories for Annex I countries, among which EU member states. These inventories identify process emissions from clinker production (category 2.A.1), but not fossil fuel emissions, which are gathered with other sectors. This explains why this curve is below the others and prevents from analysing energy intensity and fuel switch as emission drivers.

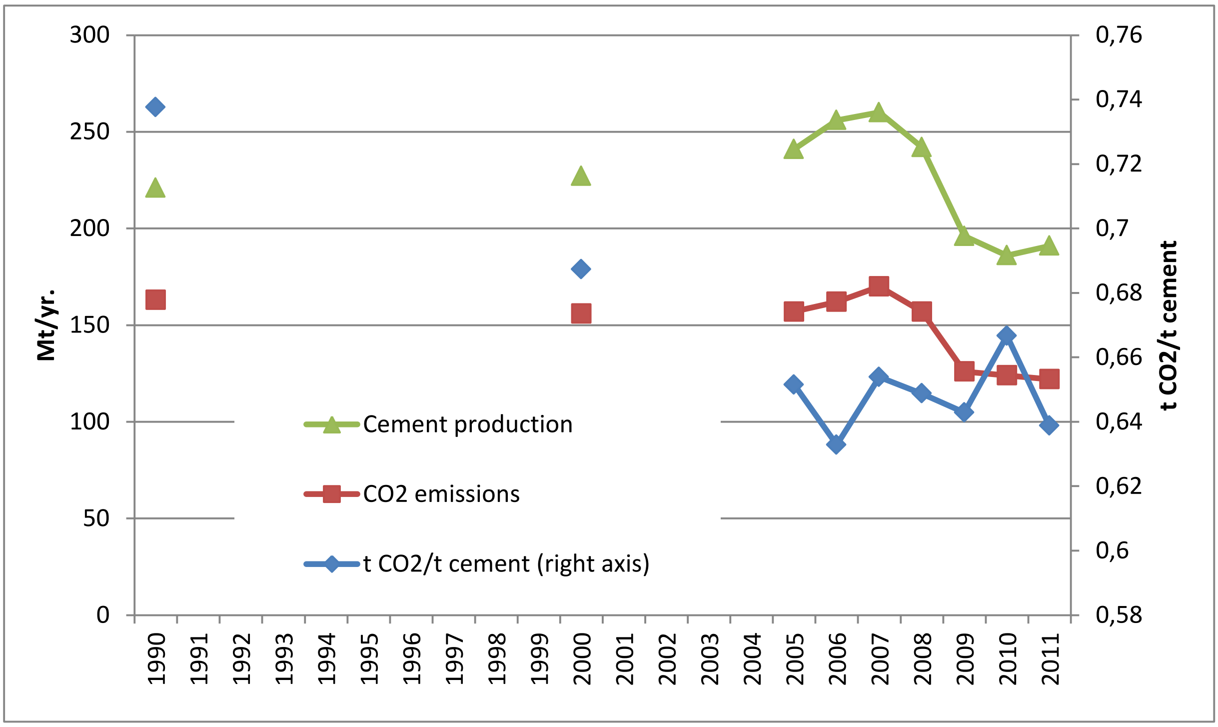
For all these reasons, we choose to rely on the GNR database.

**Figure 3-2 $CO_2$ emissions in the cement and related sectors**



## 3.4 Evidence

**Figure 3-3 Cement production and $CO_2$ emissions in the EU 28**



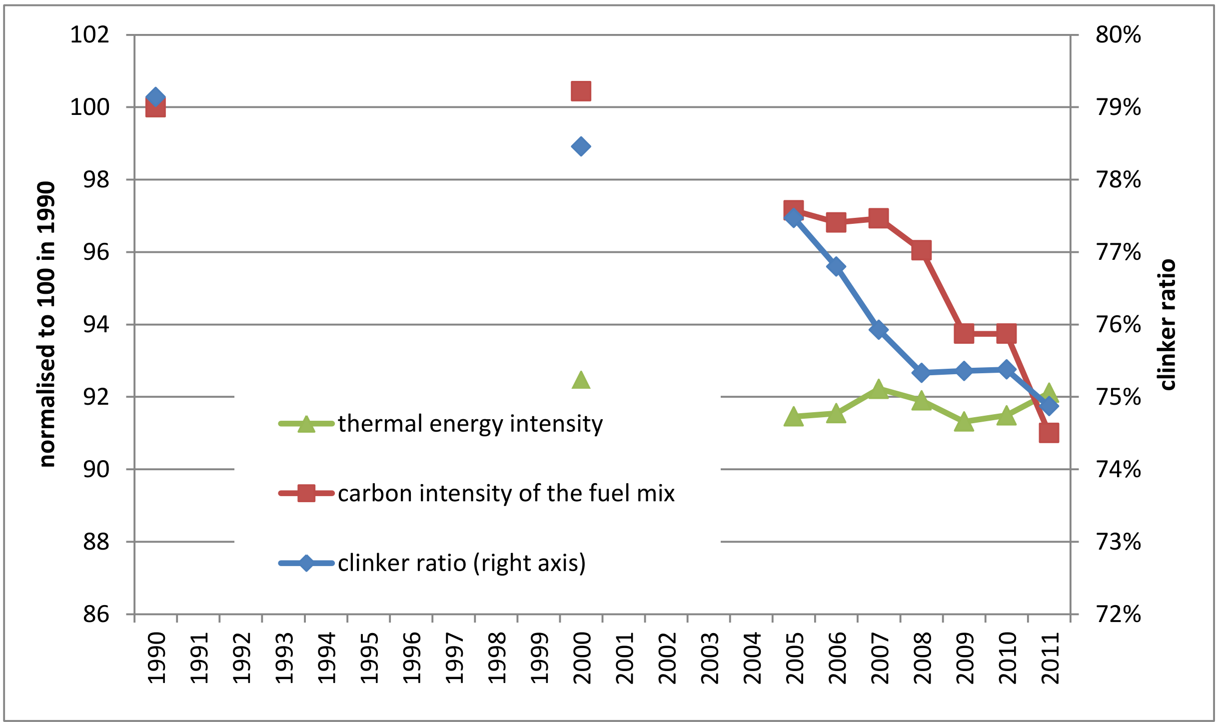

Source: authors' calculation based on WBCSD (2013) data.

Let's start by looking at $CO_2$ emissions. As shown in Figure 3-3, after being rather stable between 1990 and 2007, they drop heavily from 2007 and 2009 (from 170 to 126 Mt) then stabilise again. However, although this drop coincides with the second phase of the EU ETS, it is mainly due the recession, which entailed a large decrease in cement production (from 260 Mt in 2007 to 186 in 2010). Taking the ratio of these two series yields cement specific emission, expressed in t $CO_2$/t cement produced. It has evolved in a much less glorious way: whereas it decreased neatly from 1990 to 2000 (-5 kg $CO_2$/t cement p.a. i.e. -0.7% p.a.) and even more between 2000 to 2005 (-7 kg $CO_2$/t cement p.a. i.e. -1% p.a.), it has stalled since the start of the EU ETS: (-2 kg $CO_2$/t cement p.a. i.e. -0.33% p.a. between 2005 and 2011). Moreover, as we shall see, a change in $CO_2$ emissions reporting requirements between 2010 and 2011 entails an artificial decrease in emissions between these years. If we limit ourselves to the period 2005-2010, not concerned with this artefact, there has actually been an *increase* in specific emissions. In any case, $CO_2$ emissions per tonne of cement have been almost steady since 2005.

Of course, on the sole basis of these data, one cannot exclude that the EU ETS reduced emissions already in 2005, its first year of operation, but given the investments needed both in cement plants (to increase energy efficiency, to process slag or fly ash or to allow burning more biomass and waste), or to convince customers to switch to cements with a lower clinker content, this seems unlikely unless one thinks that the reductions were triggered earlier. We cannot completely exclude this possibility but proxy data like process emissions from the UNFCCC and fossil fuel emissions in the non-metallic minerals sectors from the IEA do not show any particular inflexion between 2004 and 2005.

How did the drivers that we have presented in section 3.2.1 contribute to the evolution of cement $CO_2$ intensity? Cement production (driver n° 3) did not, by definition (except indirectly – see below), and neither did $CO_2$ capture and storage since it is still at a pilot stage. Figure 3-4 below displays the evolution of the remaining three drivers: energy intensity of clinker production (driver n° 1.1), carbon intensity of the fuel mix (driver n° 1.2) and clinker ratio (driver n°2).

**Figure 3-4 Drivers of cement specific emissions in the EU 28**




Source: authors' calculation based on WBCSD (2013) data.

Interestingly, they have evolved very differently.

**Energy intensity** has decreased by almost 8% between 1990 and 2000, but by only one more per cent between 2000 and 2005 and has actually slightly increased since then. On the basis of this evidence, we can reasonably conclude that **the EU ETS has not reduced the energy intensity of clinker production**. This is confirmed by the stability of the different kiln types since 2005, presented in table 1, which shows the share of each of them, ranked from the most efficient on the left to the least efficient on the right.

**Table 1. Clinker volume by kiln type in the EU 28 (%)**

| Year | Dry with preheater and precalciner (%) | Dry with preheater without precalciner (%) | Dry without preheater (long dry kiln) (%) | Mixed kiln type (%) | Semi-wet/semi dry (%) | Wet (%) |
|---|---|---|---|---|---|---|
| 1990 | 0.23 | 0.36 | 0.06 | 0.11 | 0.15 | 0.09 |
| 2000 | 0.34 | 0.34 | 0.03 | 0.11 | 0.12 | 0.06 |
| 2005 | 0.42 | 0.32 | 0.02 | 0.09 | 0.09 | 0.05 |
| 2006 | 0.43 | 0.32 | 0.02 | 0.09 | 0.09 | 0.05 |
| 2007 | 0.43 | 0.32 | 0.02 | 0.09 | 0.08 | 0.05 |
| 2008 | 0.43 | 0.33 | 0.03 | 0.09 | 0.08 | 0.05 |
| 2009 | 0.46 | 0.32 | 0.02 | 0.08 | 0.07 | 0.04 |
| 2010 | 0.45 | 0.33 | 0.04 | 0.07 | 0.07 | 0.04 |
| 2011 | 0.44 | 0.33 | 0.04 | 0.07 | 0.07 | 0.05 |

Source: WBCSD (2013)

While the share of the most efficient technology (Dry with preheater and precalciner) increased from 23% to 42% from 1990 to 2005, i.e. +1.2 percentage points p.a., it only increased by 2 percentage points between 2005 and 2011, i.e. +0.3 percentage points p.a. Likewise, the share of the least efficient technologies decreased much less since the start of the EU ETS than before.

The share of the most efficient kilns increased, albeit only very slowly since 2005. Why, then, did energy efficiency decrease during this period? The two most likely explanations (which are not exclusive) are that the recession has pushed many kilns to operate well below their nominal capacity, which degrades energy efficiency, and that the share of biomass waste (to which will turn now) has increased, which also diminishes energy efficiency, because some of these waste contain water which must be evaporated.

Conversely, the **carbon intensity** has been stable between 1990 and 2000 before decreasing by 3 per cents until 2005 and by 6 more points until 2011. Notice, however, than the 2 per cents drop between 2010 and 2011 includes a statistical artefact: until 2010, waste including both biomass and fossil fuels (e.g. used tires, which are partly made from latex and partly from oil) were treated as fossil fuels, i.e. all the $CO_2$ emitted was reported. Since 2011, only the $CO_2$ originated from the fossil part of these wastes is included, which, according to industry experts, explains much of the drop in 2011.

Without this artefact, the carbon intensity of clinker production has decreased at the same rate between 2000 and 2005 and between 2005 and 2010 (0.7 percentage points p.a.). Without the inclusion of the cement sector in the EU ETS, this decrease may have been slower, in particular because other sectors (mainly electricity generation) may have burnt some of the biomass fuel which was actually used by the cement sector. Still, **there is no clear impact of the EU ETS on carbon intensity**. The explanation may be that the $CO_2$ price has been insufficient: as explained in a forthcoming Climate Strategies (2013) report, even with a $CO_2$ price of 20€ (higher than the observed average spot price), replacing a wet or semi-wet kiln with a state-of-the-art kiln leads to cost savings of 4.6 and 1.4 €/t clinker respectively, which may be insufficient for justifying retrofitting. Moreover, one cannot exclude a perverse impact from the free allowance allocation, by which some companies would refrain from reducing emissions, anticipating future allocation to be proportional to future emissions.

Finally, the **clinker ratio** has decreased only slightly (by less than one percentage point) between 1990 and 2000, and at a faster rate since then, especially between 2005 and 2008 (by 2.2 percentage points). After a phase of stability between 2008 and 2010, the ratio decreased again in 2011, by 0.5 percentage points. In average, it decreased annually by 0.09 percentage points over 1990-2000, by 0.24 percentage points over 2000-2005 and by 0.55 percentage points over 2005-2011. Hence, **the EU ETS seems to have significantly reduced the clinker ratio**. If the ratio had followed its 2000-2005 trend, it would have been around 2 percentage points higher than its actual value in 2011, resulting in emissions approximately 2% higher. However, we cannot rule out another explanation, i.e. the massive increase in steam coal and petcoke price (the two main energy carriers used to produce clinker) since 2000. Both prices have roughly doubled from 2003-4 to 2010-11 (Cembureau, 2011, p. 31), reinforcing the profitability of using substitutes rather than clinker.

# 4 Carbon leakage and competitiveness of cement and steel industries under the EU ETS

## 4.1 Introduction

Unfortunately, the existing evidence about the amount of carbon leakage and competitiveness losses which can be expected from a given climate policy is not conclusive (cf. section 4.2 below): among *ex ante* studies, general equilibrium models point to a positive but limited leakage at the aggregate level (typically from 5% to 25%) while for some carbon-intensive sectors like steel or cement, a higher leakage rate is sometimes forecast (Oikonomou et al., 2006; Demailly and Quirion, 2006), although this is not always true: Demailly and Quirion (2008) find a 0.5%-25% uncertainty range for steel. Moreover, the few existing *ex post* studies do not bring consistent conclusions. Finally, *ex ante* as well as *ex post* studies assess different policy scenarios in different contexts so cannot be directly used to assess the impact of the EU ETS.

The present section aims at filling this gap by assessing econometrically operational leakage[2] over the first two phases of the EU ETS, in the two most emitting manufacturing industry sectors: cement and steel. The methodology is to econometrically estimate a relation, obtained via an analytic model, between net imports (imports minus exports) and the carbon price, controlling for other factors that may influence net imports such as economic activity in and outside Europe. Using two different econometric techniques which provide consistent results, we conclude that net imports of cement and steel have been driven by domestic and foreign demand but not by the $CO_2$ allowance price, falsifying the claim that the ETS has generated leakage, at least in the short run.

## 4.2 Literature review

Whereas carbon pricing is relatively new, environmental regulations on local pollutants have a much longer history. For example the Clean Air Act was implemented in the US during the seventies, well before climate change was on the agenda. Therefore the first studies empirically assessing the impacts of environmental regulations on trade dealt with local pollution issues and tested the pollution haven hypothesis/effect (Kalt, 1988; Tobey, 1990; Grossman and Krueger, 1993; Jaffe et al., 1995). The migration of dirty industries to countries with lower environmental standards (pollution havens) depends both on the environmental regulatory gap and on trade tariffs. In the pollution haven hypothesis (respectively effect), the first (respectively the second) factor is hold constant[3]. The pollution haven hypothesis was a major concern during the negotiations of the North American Free Trade Agreements in the nineties (Jaffe et al., 1995), but as the decrease in trade tariffs seems to slow down, the pollution haven effect is nowadays a more relevant concern (and carbon leakage due the EU ETS would be a ‘carbon haven effect’ (Branger and Quirion, 2013a)).

The prevailing conclusion of the pollution haven literature is that environmental regulations have a small to negligible impact on relocations (Oikonomou et al., 2006). After a first wave of inconclusive works (Eskeland and Harrison, 2003), a second generation of studies have demonstrated statistically significant but small pollution haven effects using panels of data and industry or country fixed effects (Levinson and Taylor, 2008). Many reasons were invoked to explain why the widely believed fear of environmental relocations was not observed. Some pointed that environmental regulations are not a main driver of relocations contrarily to economic growth in emerging countries (Smarzynska, 2002), or that pollution abatement represents a small fraction of costs compared to other costs or barriers which still favour production in industrialized countries (Oikonomou et al., 2006): tariffs, transport costs, labour productivity, volatility in exchange rate, political risk, etc. Other highlighted that heavy

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[2] A distinction can be made between leakage that occurs in the presence of capacity constraints in the short term, termed *operational leakage* and leakage which occurs in the longer term via the impacts of the EU-ETS on investment policy, termed *investment leakage* (Climate Strategies, 2013).

[3] For a more elaborated presentation and discussion of these notions, cf. Kuik et al. (2013).

industries are very capital-intensive and tend to locate in capital-abundant countries, or that their capital intensity made them less prone to relocate than 'footloose' industries (Ederington et al., 2003). Finally, the Porter hypothesis (Porter and Van der Linde, 1995), implying that regulations bring cost-reducing innovations, was also mentioned.

The pollution haven literature is mostly related to command-and-control regulations for local pollutants, whereas the EU ETS is a cap-and-trade system for carbon emissions. Some studies evaluated policies which are closer to the EU ETS such as environmental taxation in some European countries. Miltner and Salmons (Miltner and Salmons, 2009) studied the impact of environmental tax reforms (ETR) on competitiveness indicators for 7 European countries and 8 sectors and found that, out of 56 cases (7 countries and 8 sectors studied), the impact of ETR on competitiveness was insignificant in 80% of the cases, positive in 4% and negative for only 16% of the cases (Miltner and Salmons 2009). However, energy-intensive sectors benefited from exemptions and lower taxation rates. Costantini and Mazzanti (2012) used a gravity model to analyse the impact on trade flows of environmental and innovation policies in Europe and revealed a Porter-like mechanism: when the regulatory framework is well followed by private innovation, environmental policies seem to foster rather than undermine export dynamics.

The question of carbon leakage was also a relevant issue for the Kyoto protocol. Aichele and Felbermayr (2012) assessed the impact of the Kyoto protocol on $CO_2$ emissions, $CO_2$ footprint and $CO_2$ net imports, using a differences-in-differences approach. They conclude that the Kyoto protocol has reduced domestic emissions by about 7% but has not changed the carbon footprint: $CO_2$ net imports increased by about 14%. Although they do not explicitly formulate it, their results lead to a carbon leakage estimation of about 100%, contrasting with the other empirical studies. However, two caveats are in order. First, China became a member of the WTO in 2002, just when most developed countries ratified the protocol. Since most $CO_2$ net imports are due to trade with China, the rise in net imports may well be due to China WTO membership rather than to Kyoto. Second, apart from those covered by the EU ETS, countries with a Kyoto target have not adopted significant policies to reduce emissions in manufacturing industry. Hence, if Kyoto had caused leakage (through the competitiveness channel), it should show up on the $CO_2$ net imports of countries covered by the EU ETS rather than on $CO_2$ net imports of countries covered by a Kyoto target; yet the authors report that EU membership does not increase $CO_2$ imports, when they include both EU membership and the existence of a Kyoto target in the regression.

Some papers use econometric models to empirically investigate the impact of climate policies on heavy industries *ex ante*, using energy prices as a proxy. Gerlagh and Mathys (2011) studied the links between energy abundance and trade in 14 countries in Europe, Asia and America. They found that energy is a major driver for sector location through specialisation, but do not quantify relocations under uneven carbon policies. Aldy and Pizer (2011) focused on the US but used a richer sectoral disaggregation. The authors conclude that a \$15 $CO_2$ price would not significantly impact the US manufacturing industry as a whole, but that some sectors would be harder hit with a decrease of about 3% in their production.

The EU ETS has constituted a subject of research for a body of empirical studies on different topics: abatement estimation (Ellerman and Buchner, 2008; Delarue et al., 2008), impact of investment and innovation (Calel and Dechezleprêtre, 2012; Martin et al., 2012b), distributional effects (Sijm et al. 2006, de Bruyn et al. 2010, Alexeeva-Talebi 2011), determinants of the $CO_2$ price (Alberola et al., 2008; Mansanet-Bataller et al., 2011; Hintermann, 2010), and carbon leakage.

So far, the few existing empirical *ex post* studies have not revealed any statistical evidence of carbon leakage and competitiveness losses for heavy industries in the EU ETS. Zachman et al. (2011), using firm level panel data and a matching procedure between regulated and unregulated firms, found no evidence that the ETS affected companies' profits. Studying the impact of carbon price on trade flows, several studies found no evidence of competitiveness-driven operational leakage for the different sectors at risk of the EU ETS: aluminium (Reinaud, 2008a; Sartor, 2013; Ellerman et al., 2010; Quirion, 2011), oil refining (Lacombe, 2008), cement and steel (Ellerman et al., 2010; Quirion, 2011).

Our work goes beyond the above-mentioned studies on several points. First, more data is available as the EU ETS is entering its third phase after eight years of functioning. Second, we introduce a new variable as a proxy for demand outside the EU, which improves the explanatory power of the econometric model. Third, the estimated equations are based on a structural economic model. Finally, we use several time-series regression techniques, to assess the results robustness.

## 4.3 Industry contexts

Cement and steel share the common aspect to be heavy industries impacted by the EU ETS. They are the two largest $CO_2$ emitters among European manufacturing sectors, with respectively 10% and 9% of the allowances allocations in the EU ETS (Kettner et al., 2013). However they rank differently along the two dimensions generally retained to assess whether a sector is at risk of carbon leakage, i.e. carbon intensity and openness to international trade (Hourcade et al., 2007; Juergens et al., 2013): cement is very carbon-intensive but only moderately open to international trade while steel features lower carbon intensity but higher trade openness.

### 4.3.1 Cement

As we have seen in section 3.2, calcination of limestone and burning of fossil fuel (mainly coal and petcoke) make the cement manufacturing process very carbon-intensive (around 650 kg of $CO_2$ per tonne). Cement production embodies 5% of worldwide emissions.

The raw material of cement, limestone, is present in abundant quantities all over the world. Besides, the value-added per tonne of cement is relatively low. Because of these two features, cement is produced in virtually all countries around the world and is only moderately traded internationally (only 3.8% of cement was traded internationally in 2011 (ICR, 2012)). China represents the lion's share of cement consumption and production around the world, due to the large scale developments and infrastructure build-up projects that the

Chinese government is undertaking. In 2011, 57% of the 3.6 billion tonnes of cement were produced in China, and the second country producer, the EU, was far behind with 8% of the world production (ICR, 2012).

Cement is a sector where international competition is low (Selim and Salem, 2010). Because of low value per tonne and market concentration, important price differences remain even within Europe (Ponssard and Walker, 2008). Prices are higher and producers have more market power inland than near the coasts because transportation costs are much lower by sea than by road.

Clinker is the major raw material for cement. Its production accounts for most of the $CO_2$ emitted in the manufacturing process, and it can be transported more easily than cement since its handling emits less dust. Therefore in the cement sector, carbon leakage is more likely to happen through clinker trade than through cement trade.

### 4.3.2 Steel

Steel is produced either from iron ore and coal using the Blast Furnace - Basis Oxygen Furnaces (BF-BOF) route, for around 70% of world production, or from steel scrap in Electric Arc Furnaces (EAF), for 29% of world production in 2011 (WSA, 2012). The BOF process is roughly five times more carbon-intensive than the EAF but the share of the latter is limited by scrap availability. Steel is very carbon-intensive and accounts for 6% of worldwide emissions (CarbonTrust, 2011b).

Like cement but to a lesser extent, China embodies most of the world steel consumption and production: 45% of the 1,518 million of tonnes of 2011 world production (followed by the EU with 12%). Steel has a much higher value-added per tonne than cement (roughly ten times more) and is thus more widely traded. In 2011, 31% of finished steel products were internationally traded (WSA, 2012).

Steel prices, though set on a bilateral basis, are more homogenous than cement prices and steel futures are even sold in the London Metal Stock exchange. International competition is higher in steel than in cement (Ecorys, 2008).

## 4.4 Methodology and data

Our goal is to study the impact of carbon price on competitiveness-driven operational leakage, at a geographically aggregated level (European Union versus the rest of the world) for two sectors ‘deemed to be exposed at risk of carbon leakage’: cement and steel.

If competitiveness-driven carbon leakage occurs, it is through the trade of carbon intensive products. An indicator of carbon leakage is then a change in international trade flows of carbon-constraint products (measured by net imports, or imports minus exports).

### 4.4.1 A simple analytical model

We build the simplest possible model able to feature carbon leakage. Industries of two regions, *e* (Europe) and *r* (rest of the world) are in perfect competition. Therefore the price in each region is equal to the marginal cost. The perfect competition may seem a bold hypothesis, especially for the cement sector which, at least in some countries, is rather concentrated. However, introducing imperfect competition would significantly complicate the model without necessarily bringing new insights. For example, Cournot competition[4] may reduce the sensitivity of net imports to a price asymmetry and thus leakage, but the results would then become very sensitive to the shape of the demand curve (Demailly and Quirion, 2008).

There is no product differentiation. This assumption, like perfect competition, is chosen for the sake of simplicity. Further, we neglect transportation costs for two reasons. First, their introduction would hinder the ability to produce a simple equation to estimate. Second, the estimation of the model with transportation costs causes endogeneity problems (net imports of cement and steel are drivers of shipping costs). Finally, we assume fixed demand, i.e. world demand is not dependent on world price p.

We suppose production costs are quadratic, so marginal costs are linear. The extra cost due to the climate policy (only in region *e*) is strictly proportional to production. The marginal costs of production are then

$$p = ci_e + CO2Cost + cs_e q_e \qquad (1)$$

in Europe and

$$p = ci_r + cs_r q_r \qquad (2)$$

in the rest of the world, where $q_e$ and $q_r$ are the production levels in regions *e* and *r*, $CO2Cost$ is the carbon cost times specific emissions[5] plus the abatement cost per unit produced, if any, $ci_e$ and $cs_e$ (respectively $ci_r$ and $cs_r$) are the intercept (*ci*) and slope (cs) parameters of the production cost in Europe (respectively the rest of the world).

Trade occurs between the two regions, and we note $q_m$ the net imports from region *r* to region *e*. Demands in regions *e* and *r* are by definition:

$$d_e = q_e + q_m \qquad (3)$$

$$d_r = q_r - q_m \qquad (4)$$

$cs_e$×(3) - $cs_r$×(4) leads to:

$$(cs_e + cs_r)q_m = cs_e d_e - cs_r d_r - cs_e q_e + cs_r q_r \qquad (5)$$

Using (1) and (2) to substitute respectively $cs_e\, q_e$ and $cs_r\, q_r$ in (5), and then dividing by ($cs_e$ + $cs_r$) we finally obtain a linear equation linking the level of net imports to the $CO_2$ cost and the demands:

[4] Cournot competition is an economic model in which there are a limited number of firms which have market power, i.e. each firm's output decision affects the good's price, and which maximize profit given their competitors' decisions.

[5] Hence we assume that firms maximise profit taking the full opportunity cost of $CO_2$ allowances into consideration. If on the opposite firms only take into account the cost of the $CO_2$ allowances they must buy, no impact cn be expected since cement and steel have benefited from a large over-allocation in the period considered.

$$q_m = \frac{1}{cs_e + cs_r} CO2Cost + \frac{cs_e}{cs_e + cs_r} d_e - \frac{cs_r}{cs_e + cs_r} d_r + \frac{ci_e - ci_r}{cs_e + cs_r} \quad (6)$$

### 4.4.2 Estimated equation

Assuming further than *CO2Cost* is a linear function of the $CO_2$ price (which is granted in sectors where specific abatement is limited, as shown in section 3 above) we can transform equation (6) into testable equations as follows:

$$NImp_C = \alpha_C CO2price + \beta_C Cons_{EU} + \gamma_C Ind_{BRICS} + const_C + \varepsilon_C \quad (7)$$

for cement, and:

$$NImp_S = \alpha_S CO2price + \beta_S Ind_{EU} + \gamma_S Ind_{BRICS} + const_S + \varepsilon_S \quad (8)$$

for steel, where $\alpha_c$, $\beta_c$, $\gamma_c$, $\alpha_s$, $\beta_s$ and $\gamma_s$ are the coefficients to be estimated while $\varepsilon_c$ and and $\varepsilon_s$ are the residuals, which we assume to be IID, that is later to be tested.

The variables are (the source of the data will be detailed in 4.4):

- *Net imports* (*NImp*), or imports minus exports, for each of the two sectors, between the EU27 and the rest of the World. This is the predicated variable, and a proxy for operational leakage. The choice of the geographical delimitation (EU27) is not trivial. Indeed in 2007, the two new member states, Bulgaria and Romania, joined the EU ETS. One year later, the EU ETS welcomed Norway, Iceland and Liechtenstein, countries which are not in the European Union. As the purpose of this article is to study the impact of the EU ETS on competitiveness and leakage, another option was to consider an EU ETS geographical coverage changing over time. This would have posed econometric problems since it would have introduced shocks in the time series. Since these five countries do not produce a significant share of European production, we judge that it was a preferable option not to take these changes into account.
- CO2 price. This is the main regression variable. In presence of operational leakage due to competitiveness losses, a positive relation is expected. Indeed, a high carbon price would induce an increase in the production cost of European products, a loss of market share of European industries vis-à-vis their foreign competitors, and an increase in net imports. We consider the EUA future price (one year ahead) for two reasons. First, contrary to the spot price, it did not collapse in 2007, which would bias the econometrical estimation. Creti et al. (2012); Bredin and Muckley (2011); Conrad et al. (2012) use the future price for the same reason. Second, future prices were available since 2004 (contrary to 2005 for spot prices), which adds one more year (or twelve more points) to the time series and then makes the econometric estimation more robust.
- EU industrial output, EU construction index and BRICS industrial output (*$Ind_{EU}$, $Cons_{EU}$ and $Ind_{BRICS}$*). The industrial output is a proxy for the industrial economic activity and therefore the demand side (either domestic or foreign). For cement, we use the European construction index instead of the European industrial output to proxy the demand as construction is the main outlet for cement. We did not find a satisfactory

construction index for the BRICS so we used the industrial output for both steel and cement. An increase in local demand is expected to increase the demand for imports and reduce production capacities available for exports. We therefore expect a positive (respectively negative) relation for the European (respectively BRICS) industrial output. We chose to focus on BRICS countries instead of taking an aggregated industrial production index for the rest of the world because such a global index does not exist to our knowledge. Moreover BRICS countries are the engine of global economic growth: from 8% in 1999, they represented in 2011 20% world GDP. The consumption of cement and steel in BRICS countries (and especially in China) has soared in the last decade. They are not the major destination of EU27 steel exports, however they are the origin of a noticeably part of EU27 cement and steel imports (China and Russia for steel, China for cement especially between 2005 and 2008) as well as cement exports recently (Russia and Brazil).

To take into account the fact that the potential impact of carbon price on net imports is not instantaneous but necessitates some time (time between production and sale), we introduce a lag in the dependant variables. We select a lag of three months since it brings the best fit[6], as measured by the usual indicators ($R^2$ for the Prais-Winsten regression and the AIC for the ARIMA regression).

## 4.5 Econometric techniques

Two aspects are potential barriers to the validity of econometric estimations in our context: endogeneity and the issue of autocorrelation of residuals, since we work on time series data.

First let's consider the thorny issue of endogeneity. It is necessary that variables aimed at explaining the variations of net imports are truly exogenous to validate our econometrical modelling. It would not be the case if the net imports of cement or steel impacted these explanatory variables. Cement and steel sectors each stand for less than 10% of the covered emissions in the EU ETS. As most of the production is consumed within the EU, net imports variations induce much less important production variations. It is therefore highly likely that net imports variations do not impact the carbon price.

Another source of endogeneity would be that an omitted variable would impact both our main regression variable, the $CO_2$ price, and the predicated variable. Among the price determinants of carbon price, one can cite the economic activity (which is in the regression with *IndEU* or *ConsEU*), political decisions, energy prices (mainly coal and gas[7]) and unexpected weather variations[8] (Alberola et al., 2008; Hintermann, 2010). It seems unlikely that political decisions related to the EU ETS and unexpected weather variations would impact net imports of cement and steel otherwise than potentially through carbon price.

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[6] The results are very robust to a change in the lag (from 1 to 5 months), except for cement in the ARIMA regressions.

[7] An increase in coal price (resp. gas price) makes this source of energy less attractive for electricity production. Therefore the emissions are lower (resp. higher) than expected and the carbon price decreases (resp. increases).

[8] Because unexpected cold waves and heat waves induce generally using very carbon intensive power plants.

Energy prices affect production costs but we suppose that the effect is the same for production outside Europe because prices are determined on a global scale for coal and petcoke, the main energy carriers used for cement and steel production. Therefore the effect would be compensated between imports and exports.

A simple linear regression would give spurious results because of a strong autocorrelation of error terms, as in many time series data. As the Augmented Dickey Fuller shows, all the time series are I(1), as we cannot reject the hypothesis of a unit root for the time series but we can for their first difference (see results in annex). To treat the question of autocorrelation of residuals, we use two different methods. The first one is Prais-Winsten estimation, which is an improvement of the Cochrane-Orchutt algorithm[9]. The second one is the classically used model in time series analysis, the ARIMA(p,1,q) model. We identify the ARIMA(p,1,q) process that suits each dependent variable by following the Box and Jenkins methodology and found ARIMA(5,1,3) and ARIMA(6,1,4) for respectively cement and steel. We use the Ljung-Box-Pierce test (which will be explained in further details in section 4.7.2) to evaluate the results.

Longer time series give more robust estimations, but including the carbon price on the time period 1999-2012 would give spurious results, since there is a break in the time series (this variable is at zero during 1999-2003, then positive).

We perform the first regression to have a most robust estimation of net imports depending on local and foreign demand. Then we do a second regression for the period 2004-2012 including the carbon price. Comparing the results allows assessing if the previous estimation is robust in time and examine the impact of adding a carbon price.

## 4.6 Data

All the data are monthly from January 1999 to December 2012 (168 points), except for the carbon prices taken from January 2004 to December 2012 (108 points).

- *Net imports of cement and steel for EU27* are taken from the Eurostat international trade database. For cement we take into account clinker, as this semi-finished product is more prone to carbon leakage. For Steel, we consider iron and steel in the broad sense, which includes pig iron and semi-finished steel products. The original values in 100kg are converted into Mt/year (with the formula 1Mt/year=833333.3 100kg/month).
- *$CO_2$ price*. Carbon prices are taken from *Tendances Carbone* edited by CDC Climat[10].
- *EU industrial output index* and *EU construction index* are provided by Eurostat[11]. They are both normalized to 100 in 2005.

[9] In a series of recent articles, McCallum (2010), Kolev (2011) and Zhang (2013) have concluded that most so-called ‘spurious regression’ problems are solved by applying the traditional methods of autocorrelation correction, like the iterated Cochrane-Orcutt procedure (Cochrane and Orcutt, 1949). However, other authors including Martínez-Rivera and Ventosa-Santaulària (2012), Sollis (2011) and Ventosa-Santaularia (2012) have argued that these procedures do not always avoid spurious regressions and invite to pre-test the data and first-differentiate them if they appear to be I(1). Hence we apply both methods in this paper.

[10] http://www.cdcclimat.com/-Publications-8-.html

- *BRICS industrial output*. Several steps were necessary to compute this index. First, for Brazil, Russia, India and South Africa, the productions in total manufacturing (normalized at 2005=100), were available on the Federal Reserve of Saint Louis Economic Research website[12] derived from the OECD Main Economic Indicators database. China's published industrial statistics are far from being open and the scattered available data are confusing (changes in variables, in coverage, in measurement, and in presentation). Holtz (2013) reviews the available official data and proceeds to construct a monthly industrial output series. Monthly industrial output (economy-wide constant price) are taken from this paper for the years 1999 to 2011, and extended for the year 2012 thanks to online data[13] giving annual increase rate of industrial output every month. The obtained data are cyclical: the industrial production is at its highest in December and at its lowest in January and February. We regress the log of this industrial output over time and monthly dummies to estimate seasonal factors, then we withdraw these factors from the original data to obtain a seasonally adjusted Chinese industrial output (which we normalize at 2005=100). Finally, the BRICS industrial output is the weighted mean of national industrial outputs (the weights are the 2005 GDP[14]).

## 4.7 Results

### 4.7.1 Descriptive statistics

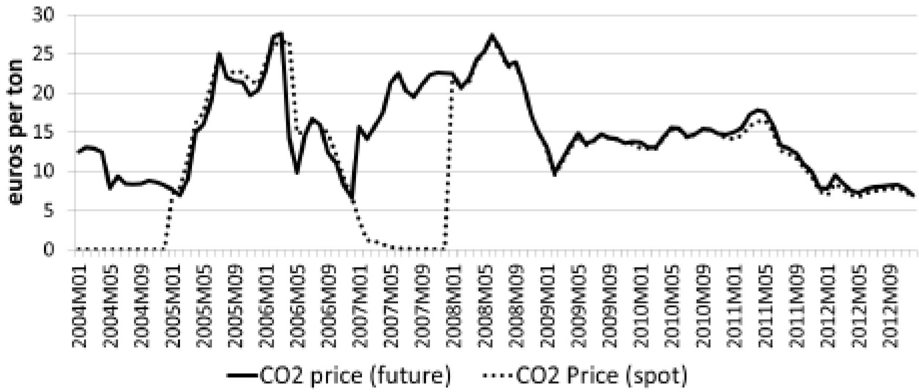
**Table 2 Summary statistics of the regression variables**

| Variable | Obs | Mean | Std dev | Min | (date) | Max | (date) |
|---|---|---|---|---|---|---|---|
| $NImp_{Cement}$ | 168 | 0.19 | 7.34 | -17.95 | Jun 2012 | 19.57 | Mar 2007 |
| $NImp_{Steel}$ | 168 | -0.35 | 13.07 | -26.56 | Aug 2012 | 35.62 | Jan 2007 |
| $CO_2price$ | 108 | 14.89 | 5.55 | 6.60 | Dec 2012 | 27.60 | Mar 2006 |
| $Cons_{EU}$ | 168 | 97.10 | 5.83 | 84.16 | Feb 2012 | 110.44 | Feb 2008 |
| $Ind_{EU}$ | 168 | 99.86 | 5.52 | 89.67 | Apr 2009 | 113.10 | Jan 2008 |
| $Ind_{BRICS}$ | 168 | 113.38 | 35.51 | 63.18 | Feb 1999 | 178.46 | Dec 2012 |

Obs=Observations Std dev=Standard deviation

[11] Production in industry and Production in construction- monthly data (extracted in April 2013).
[12] http://research.stlouisfed.org/fred2/
[13] http://www.tradingeconomics.com/china/industrial-production
[14] Source: United Nations (http://unstats.un.org/unsd/snaama/dnltransfer.asp?fID=2)

**Figure 4-1 EU allowance price**

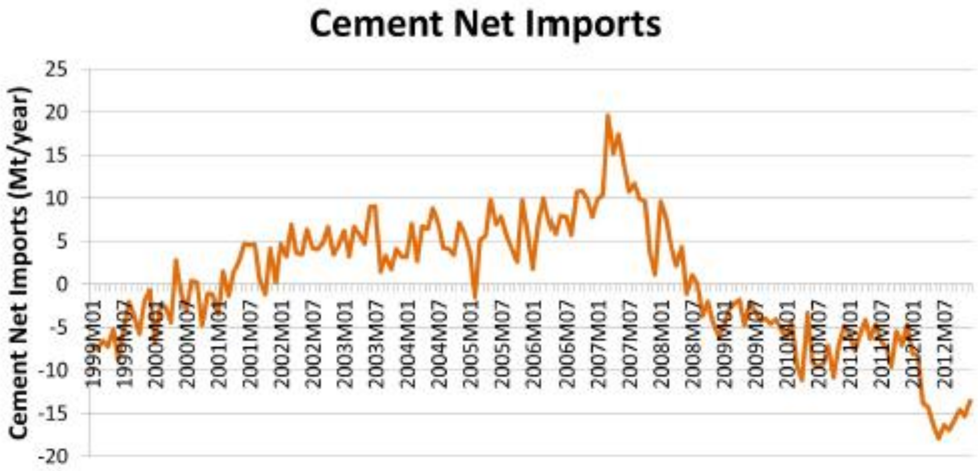



Future carbon price (see figure 3) existed in January 2004, one year before the beginning of the EU ETS in January 2005, oscillating around eight euros during this year. Then it increased rapidly during the beginning of phase I of the EU ETS to fluctuate around 25 euros between June 2005 and April 2006. The release of 2005 verified emissions suggested that most of the installations had emitted less than their number of allowances. As no banking was allowed between phase I (2005-2007) and phase II (2008-2012), this surplus of allowances led to a crash of the carbon spot price, and a severe decrease in the future price. During the second phase the EUA price rose as during the first phase to exceed 20 euros, then fell under 10 euros as it appeared that the economic crisis was going to noticeably reduce the demand for allowances. During two years from June 2009 to June 2011, the carbon price was stable between 13 and 16 euros. The carbon price fell under 5 euros six months later for several reasons (lasting of the economic crisis in Europe due to the sovereign debt crisis, interaction with other energy efficiency or renewable climate policies reducing demand), and maintained at this price for the year 2012.

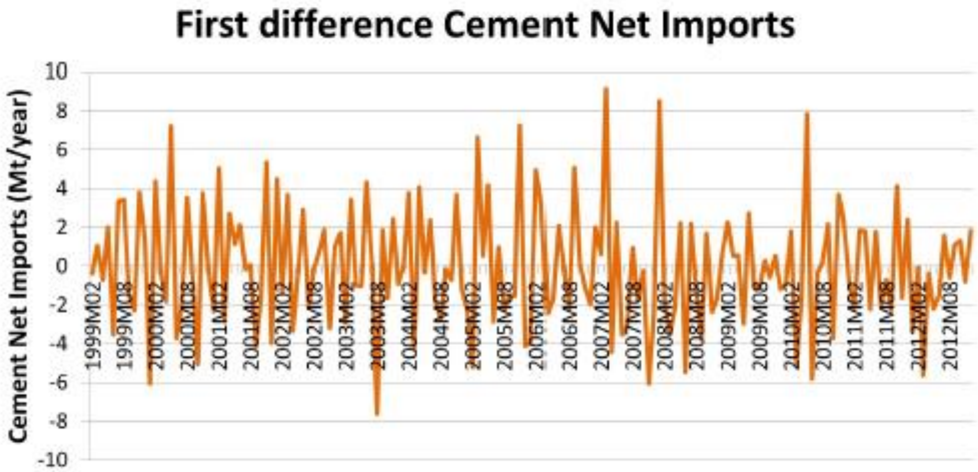
The net imports of cement (see figure 4) increasingly rose from 1999 to reach a peak in March 2007 at 20 Mt per year then continuously fell with recently a severe collapse in the beginning of 2012. Since mid-2008, the EU is a net exporter of cement whereas it was a net importer from 2001 to 2007.

The steel net imports (see figure 5a) oscillated around zero from 1999 to 2005, then the EU became a net importer from 2005 to 2008. Net imports peaked in summer 2007 with 33 Mt per year then collapsed the same year. After a rebound up to 20 Mt per year, steel net imports fell during the economic crisis. Since then, with the exception of the beginning of year 2011, the EU is a net exporter of steel.

**Figure 4-2 Cement net imports**



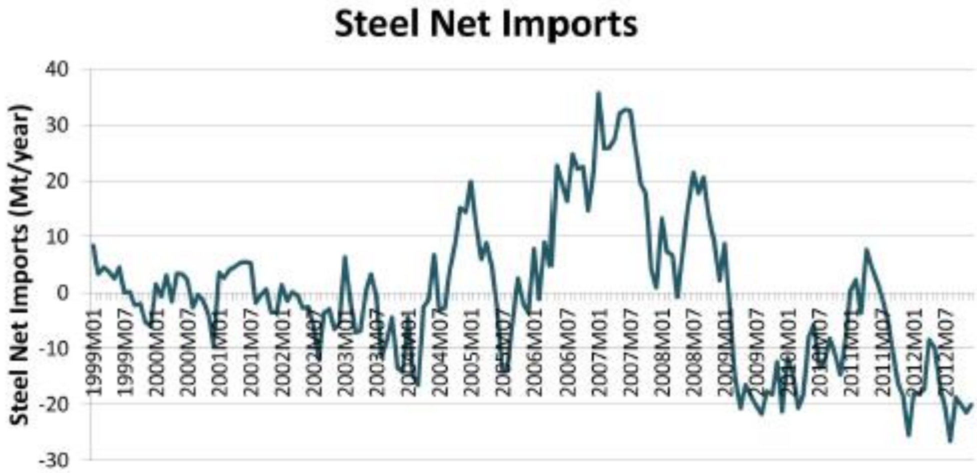

(a) Cement



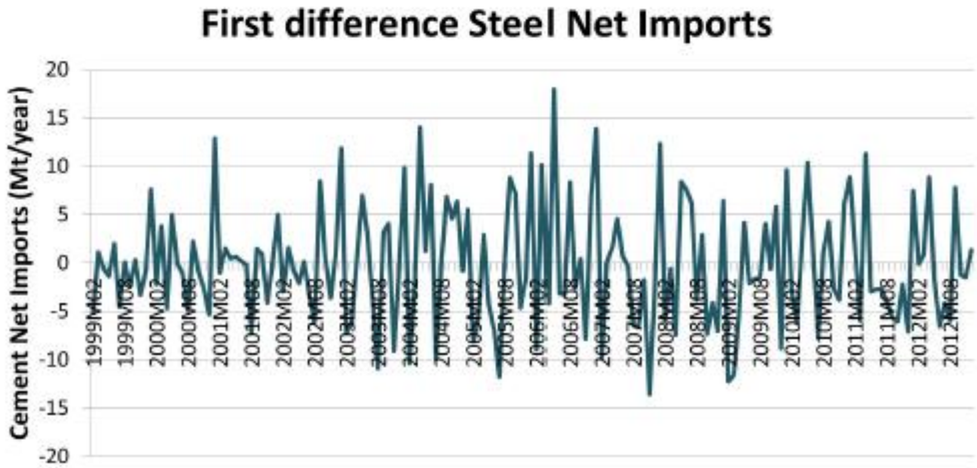

(b) Cement (first difference)

At first sight, cement and steel net imports and carbon price do not seem correlated. Most of the time, the two high carbon price periods (2005-2006 and 2008) did not coincide with high net imports. On the contrary, for these products, net imports reached their peak in 2007 while the spot carbon price was very low. Still, it was also a time of intense industrial activity in Europe, parameter which will be taken into account in the regression.

**Figure 4-3 Steel net imports**

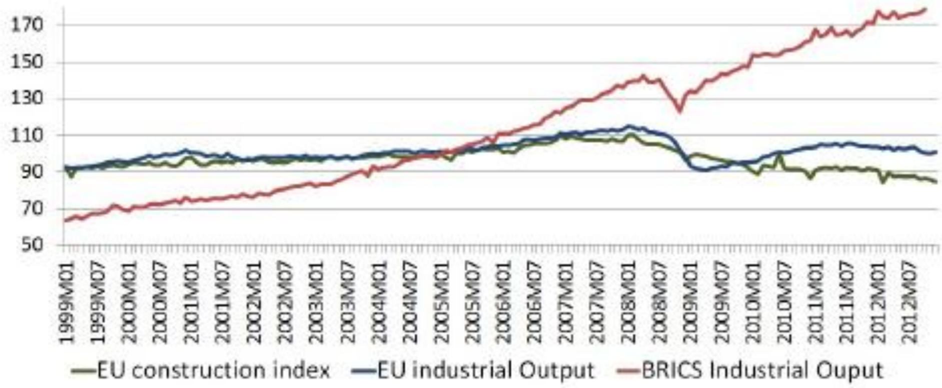



(a) Steel




(b) Steel (first difference)

**Figure 4-4 Other regression variables**




The EU industrial output slightly increased from 1999 to 2008, then collapsed during the economic recession (by about 20% in six months to be back at its level ten years before). After a rebound until 2011 without getting back to its pre-crisis level, it fell a second time. The EU construction index is very similar except it plummeted less sharply during the financial crisis though it never recovered. The BRICS industrial output presents some differences. First, contrary to the EU industrial output which has not significantly changed between 1999 and 2012, the BRICS industrial output almost tripled during the same period. Also hit by the global financial crisis, it took only a year to be back to its pre-crisis level and contrary to its European equivalent, it steadily grew since then. Year 2011 marked a discrepancy in industrial activities between Europe and the BRICS. Whereas the EU is getting bogged down in a deep economic and industrial recession, the BRICS manufacturing industries are flourishing. For econometric considerations, as the two series were before 2011 much more correlated, this outcome is also interesting to prevent an identification problem.

### 4.7.2 Regression results

The results are visible in tables 3 and 5 for the ARIMA estimations, and in tables 4 and 6 for the Prais-Winsten estimations. We recall that for each sector, two estimations are performed: one without the carbon price, on the time period 1999-2012, and one with the carbon price on the time period 2004-2012 (see part 4.5). Comparing the results with the second regression allows examining the impact of adding a carbon price.

For the ARIMA regressions, the quality of the regressions is assessed with several diagnostic tests: the log-likelihood, the Schwartz and Akaike information criterions (SIC and AIC), and the Ljung-Box-Pierce statistic (Q test) with a maximum number of lags of 40. The null hypothesis in this test is that the residuals are not autocorrelated, so the observed correlations are just a result of randomness. The critical region for rejection of the hypothesis of randomness is when $Q$ is higher than the $\alpha$-quantile of a chi-squared distribution. If we take $\alpha$ = 5%, the model is validated if "Prob>chi(40)">5%, though a higher p-value indicates that the model is better fit. For the Prais-Winsten estimations, we give the value of $R^2$ and the Durbin-Watson test (which is close to 2 if there is no autocorrelation in the residuals) before and after transformation.

In all the ARIMA regressions, the Q-tests validate that the residuals are white noise and in all the Prais-Winsten regressions, the Durbin-Watson tests assure that the residual are not autocorrelated.

Table 3: Regression estimations. Cement Net Import. ARIMA regressions

| Cement $NImp_{Cement,t}$ | 1999-2012 (1) | 2004-2012 (2) |
|---|---|---|
| $Cons_{EU,t-3}$ | 0.298 | 0.326 |
| | (2.39)** | (2.38)** |
| $Ind_{BRICS,t-3}$ | -0.344 | -0.344 |
| | (3.45)*** | (3.08)*** |
| $CO_2price_{t-3}$ | | -0.093 |
| | | (0.51) |
| N | 164 | 104 |
| Loglikelihood | -387.06 | -242.98 |
| AIC | 798.12 | 511.95 |
| BIC | 835.32 | 546.33 |
| Q | 28.57 | 23.41 |
| Prob>chi(40) | 0.91 | 0.98 |

Table 4: Regression estimations. Cement Net Import. Prais-Winsten regressions

| Cement $NImp_{Cement,t}$ | 1999-2012 (1) bis | 2004-2012 (2) bis |
|---|---|---|
| $Cons_{EU,t-3}$ | 0.580 | 0.469 |
| | (5.70)*** | (4.08)*** |
| $Ind_{BRICS,t-3}$ | -0.100 | -0.200 |
| | (4.56)*** | (5.77)*** |
| $CO_2price_{t-3}$ | | 0.036 |
| | | (0.33) |
| N | 165 | 105 |
| Adjusted $R^2$ | 0.27 | 0.48 |
| $R^2$ | 0.25 | 0.44 |
| $\rho$ | 0.71 | 0.69 |
| DW (original) | 0.75 | 0.75 |
| DW (transformed) | 2.34 | 2.19 |

Table 5: Regression estimations. Steel Net Imports. ARIMA regression

| $NImp_{Steel,t}$ | 1999-2012 (3) | 2004-2012 (4) |
|---|---|---|
| $Ind_{EU,t-3}$ | 1.025 | 1.253 |
| | (3.15)*** | (3.08)*** |
| $Ind_{BRICS,t-3}$ | 0.117 | 0.015 |
| | (0.60) | (0.06) |
| $CO_2price_{t-3}$ | | 0.103 |
| | | (0.46) |
| N | 164 | 104 |
| Loglikelihood | -501.15 | -325.88 |
| AIC | 1022.29 | 675.77 |
| BIC | 1053.29 | 707.50 |
| Q | 51.83 | 30.41 |
| Prob>chi(40) | 0.10 | 0.86 |

Table 6: Regression estimations. Steel Net Import. Prais-Winsten regressions

| Steel $NImp_{Steel,t}$ | 1999-2012 (3) bis | 2004-2012 (4) bis |
|---|---|---|
| $Ind_{EU,t-3}$ | 1.411 | 1.480 |
| | (4.81)*** | (4.20)*** |
| $Ind_{BRICS,t-3}$ | -0.184 | -0.257 |
| | (3.38)*** | (3.14)*** |
| $CO_2price_{t-3}$ | | 0.129 |
| | | (0.50) |
| N | 165 | 105 |
| Adjusted $R^2$ | 0.13 | 0.21 |
| $R^2$ | 0.14 | 0.23 |
| $\rho$ | 0.76 | 0.74 |
| DW (original) | 0.54 | 0.56 |
| DW (transformed) | 2.09 | 2.04 |

For cement, in regression (1) in table 3, both $Cons_{EU,t-3}$ and $Ind_{BRICS,t-3}$ are significant, respectively at the 5% and 1% levels. Hence, we verify that indicators of local and foreign demand carry explanatory power in cement net imports. Indeed an increase in local demand is expected to increase the demand for imports and reduce production capacities available for exports. In our model, an increase of 10 points in local demand[15] would induce an increase of about 3 million tonnes of net imports. Besides, we notice that the signs of the estimated coefficients of $Cons_{EU,t-3}$ and $Ind_{BRICS,t-3}$ are conform to the theoretical model (equation (6)). The Ljung-Box-Pierce test validates that the residuals of regression (1) are not autocorrelated.

The coefficients of $Cons_{EU,t-3}$ and $Ind_{BRICS,t-3}$ in regression (2) are very similar to the coefficients of regression (1), and statistically significant respectively at the 10% and 5% levels. This similarity indicates that the relationship between the cement net imports, local and foreign demand is robust. $CO2price_{t-3}$ is not statistically significant: the carbon price has no impact on the cement net imports variations. The results of (1)bis and (2)bis in table 4 are close to the results of (1) and (2), which gives robustness to the results. The coefficients, except for the carbon price, are all significant at the 1% level.

For steel (regression (3) in table 5), $Ind_{EU,t-3}$ is significant at the 1% level, but $Ind_{BRICS,t-3}$ is not statistically significant; whereas in (3)bis they are both significant at the 1% level. Only the local demand carries explanatory power in the ARIMA model, while both local and foreign demands do in the Prais-Winsten estimation. The impact of the local demand is bigger in the steel industry than in the cement industry[16] compared to cement net imports: an increase of 10 points in local demand would lead to an increase of about 9 million tonnes in net imports. As for cement, the similarity between the results of the two time periods implies that the relationship between the steel net imports, local and foreign demand is robust. Similarly to the cement industry, the coefficient of the carbon price $CO2price_{t-3}$ is not statistically significant.

# 5 Conclusion

Altogether, the work presented in this report points to a simple result: it looks like the EU ETS has entailed neither what its proponents have hoped for, i.e. significant emissions reduction (at least in the cement sector), nor what its opponents from the heavy industry side have feared, i.e. competitiveness losses and carbon leakage (at least in the cement and steel sectors).

This being said, a few caveat deserve to be mentioned.

First, in the cement sector, the clinker ratio has decreased more rapidly since the start of the ETS, thereby reducing $CO_2$ emissions. If the clinker ratio had followed its 2000-2005 trend, it would have been around 2 percentage points higher than its actual value in 2011, resulting in emissions approximately 2% higher.

[15] Demand is normalized to 100 in 2005.

[16] Cement net imports are a bit less than twice shorter than steel net imports (see table 2), but the estimated coefficient for local demand (approximated by EU construction or industrial indexes, both around 100) is three times bigger.

Second, there are good reasons to believe that higher abatement occurred in the electricity sector, where fuel switch and substitutions between power plants of various energy efficiencies can reduce emissions significantly.

Third, the EU ETS may have contributed to R&D about low-$CO_2$ cements, which can only deliver in the long run, but the low level of R&D in this sector, as well as the absence of co-operative R&D programme for low-$CO_2$ cement, comparable to ULCOS[17] in the steel sector, does not invite to optimism.

Fourth, even though the conclusion that no carbon leakage occurred in the short run is robust, our dataset does not allow us to conclude about long run ('investment') leakage, i.e. an increase in production capacity abroad and a decrease in production capacity in Europe *as the result of EU's climate policy*.

An open question is the role of free allocation in both results. In the first two phases of the ETS, the allocation rules differed across member states, but in all of them, free allowances were allocated to new clinker kilns through the new entrant reserve, while closing a clinker kiln meant sooner or later losing the free allowances. Moreover, grandfathering was the dominant rule for free allocation, so more allowances (per tonne of capacity) were allocated for energy-inefficient kilns than for efficient ones.

This means that free allocation provided incentives against abatement (more precisely against replacing inefficient by efficient kilns), which may contribute to the observed stagnation of energy efficiency since the start of the ETS. This also means that free allocation provided an incentive against 'investment leakage' i.e. the offshoring of production capacity.

The new allocation rules, applied since the beginning of 2013, correct some of the previous distortions since a single benchmark applies in all member states and all clinker kilns. This implies that retrofitting an inefficient plant does not reduce the amount of allowances received. Yet a potential distortion is constituted by the closure rules which take the form of activity thresholds: if an installation produce less than 50% of its historic activity level, its operator loses 50% of its allowances, and 75% of the allowances if it is less than 25%. This implies that it may be profitable to *not* close an installation. This generates an incentive, for a firm operating several plants, to operate all of them at 50% at least, rather than closing the least efficient plants and operating the others close to their nominal capacity, which could be the optimal solution without these closure rules (Climate Strategies, 2013).

Ideally, an allowance allocation system in the cement sector would allow mobilising all the drivers of $CO_2$ abatement while preventing leakage. This is not an easy task since it means incentivising the replacement of clinker by low-$CO_2$ substitutes but not by clinker imports, while being compatible with the WTO. Similarly, in the steel sector, it means incentivising a higher use of scrap but not of steel or pig iron imports. More research is needed to design such an allowance system.

[17] ULCOS stands for Ultra–Low $CO_2$ Steelmaking. It is a consortium of 48 European companies and organisations from 15 European countries that have launched a cooperative research & development initiative. http://www.ulcos.org/en/about_ulcos/home.php

Another possible explanation for the low abatement is the volatility of the $CO_2$ price which clearly hinders the required investments. A price floor system or another device to sustain the allowance price is clearly required is this respect.

## References

Abrell, J., A. Ndoye, and G. Zachmann. Assessing the impact of the EU ETS using firm level data. Bruegel Working Paper 2011/08, Brussels, Belgium, July 2011.

Aichele, R. and Felbermayr, G. (2012). Kyoto and the carbon footprint of nations. *Journal of Environmental Economics and Management*, 63(3):336.

Alberola, E., Chevallier, J., and Chèze, B. (2008). Price drivers and structural breaks in European carbon prices 2005–2007. *Energy policy*, 36(2):787–797.

Aldy, J. E. and Pizer, W. A. (2011). The competitiveness impacts of climate change mitigation policies. Working Paper 17705, National Bureau of Economic Research.

Böhringer, C., Balistreri, E. J., and Rutherford, T. F. (2012). The role of border carbon adjustment in unilateral climate policy: Overview of an energy modeling forum study (EMF 29). *Energy Economics*, 34:S97–S110.

Branger, F., Lecuyer, O., and Quirion, P. (2013). The European union emissions trading system: should we throw the flagship out with the bathwater ? CIRED Working Paper 2013-48.

Branger, F. and Quirion, P. (2013a). Climate policy and the 'carbon haven' effect. *Wiley Interdisciplinary Reviews: Climate Change*, page n/a–n/a.

Branger, F. and Quirion, P. (2013b). Would border carbon adjustment prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. CIRED Working Paper 2013-52.

Bredin, D. and Muckley, C. (2011). An emerging equilibrium in the EU emissions trading scheme. Energy Economics, 33(2):353–362.

Calel, R. and Dechezleprêtre, A. (2012). Environmental policy and directed technological change: evidence from the European carbon market.

Carbon Trust (2011a). International carbon flows - aluminium. Technical report, Carbon Trust.

Carbon Trust (2011b). International carbon flows - steel. Technical report, Carbon Trust.

Cembureau (2011). *Activity Report 2011*. Brussels.

Climate Strategies (2013) Carbon Control Post 2020 in Energy Intensive Industries. Learning from the experience in the cement sector. Energy-Intensive Industries Project Report. Forthcoming, Climate Strategies.

Cochrane, D. and Orcutt, G. H. (1949). Application of least squares regression to relationships containing auto-correlated error terms. Journal of the American Statistical Association, 44(245):32.

Conrad, C., Rittler, D., and Rotfuß, W. (2012). Modeling and explaining the dynamics of European union allowance prices at high-frequency. Energy Economics, 34(1):316–326.

Costantini, V. and Mazzanti, M. (2012). On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. Research Policy, 41(1):132–153.

Creti, A., Jouvet, P.-A., and Mignon, V. (2012). Carbon price drivers: Phase I versus phase II equilibrium? Energy Economics, 34(1):327–334.

CWR (2011). Cement - primer report. Technical report, CarbonWarRoom.

De Bruyn, S., Nelissen, D., and Koopman, M. (2013). Carbon leakage and the future of the EU ETS market. Impact of recent developments in the EU ETS on the list of sectors deemed to be exposed to carbon leakage. Technical report, CE Delft, Delft.

Delarue, E., Voorspools, K., and D'haeseleer, W. (2008). Fuel switching in the electricity sector under the EU ETS: review and prospective. Journal of Energy Engineering, 134(2):40–46.

Demailly, D. and Quirion, P. (2006). CO2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation. Climate Policy, 6(1):93–113.

Demailly, D. and Quirion, P. (2008). European emission trading scheme and competitiveness: A case study on the iron and steel industry. Energy Economics, 30(4):2009–2027.

EAEII (2010). European alliance of energy intensive industries opposes EU unilateral move to -30%. Press release, European Alliance of Energy Intensive Industries.

Ecofys, W. B. . (2013). Mapping carbon pricing initiatives. Technical report, Ecofys and World Bank.

Ecorys (2008). Study on the competitiveness of the European steel sector. Technical report, Ecorys.

Ederington, J., Levinson, A., and Minier, J. (2003). Footloose and pollution-free. Working Paper 9718, National Bureau of Economic Research.

Egenhofer et al. (2011) The EU Emissions Trading System and Climate Policy Towards 2050: Real Incentives to Reduce Emissions and Drive Innovation? Centre for European Policy Studies (CEPS)

Ellerman, A. D., S. M. Feilhauer. 2008. *A Top-down and Bottom-up Look at Emissions Abatement in Germany in Response to the EU ETS.* Massachusetts Institute of Technology. Center for Energy, and Environmental Policy Research. MIT Center for Energy and Environmental Policy Research.

Ellerman, A. D. and Buchner, B. K. (2008). Over-allocation or abatement? A preliminary analysis of the EU ETS based on the 2005–06 emissions data. Environmental and Resource Economics, 41(2):267–287.

Ellerman, D., Convery, F., and de Perthuis, C. (2010). Pricing Carbon : The European Union Emissions Trading Scheme. Cambridge, UK, Cambridge university press edition.

Eskeland, G. S. and Harrison, A. E. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. Journal of Development Economics, 70(1):1–23.

European Commission (2012). The state of the European carbon market in 2012. Technical Report COM(2012) 652, European Commission.

Gerlagh, R. and Kuik, O. (2007). Carbon leakage with international technology spillovers. SSRN Scholarly Paper ID 979915, Social Science Research Network, Rochester, NY.

Gerlagh, R. and Mathys, N. (2011). Energy abundance, trade and industry location. Nota di Lavoro 03-11, FEEM.

Grossman, G. and Krueger, A. (1993). Environmental impact of a north American free trade agreement. In The Mexico US Free Trade Agreement. Cambridge, Massachusetts, MIT press edition.

Hintermann, B. (2010). Allowance price drivers in the first phase of the EU ETS. Journal of Environmental Economics and Management, 59(1):43–56.

Holmes, P., Reilly, T., and Rollo, J. (2011). Border carbon adjustments and the potential for protectionism. Climate Policy, 11(2):883–900.

Hood, C. (2010). Reviewing existing and proposed emissions trading systems. IEA information paper, IEA.

Hourcade, J.-C., Demailly, D., Neuhoff, K., and Sato, M. (2007). Differentiation and dynamics of EU ETS competitiveness impacts. Technical report, Climate Strategies, Cambridge, UK.

ICR (2012). Global cement report. Technical report, International Cement Review.

Jaffe, A. B., Peterson, S. R., Portney, P. R., and Stavins, R. N. (1995). Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? Journal of Economic literature, 33(1):132–163.

Juergens, I., Barreiro-Hurlé, J., and Vasa, A. (2013). Identifying carbon leakage sectors in the EU ETS and implications of results. Climate Policy, 13(1):89– 109.

Kalt, J. (1988). The impact of domestic environmental regulatory policies on U.S. international competitiveness. In International Competitiveness. Ballinger Publishing Company.

Kettner, Claudia, Daniela Kletzan-Slamanig, Angela Köppl. 2013. The EU Emission Trading Scheme – Sectoral allocation patterns and factors determining emission changes. WIFO Working Papers, No. 444

Kolev, G. I. (2011). The "spurious regression problem" in the classical regression model framework. Economics Bulletin, 31(1):925–937.

Kuik, O., F. Branger, P. Quirion (2013). *International competitiveness and markets. The current policy mix*. Report for the EU FP7 Cecilia2050 project (Task 2.8).

Lacombe, R. (2008). Economic impact of the European Union emissions trading system : Evidence from the refining sector. MIT master thesis.

Levinson, A. and Taylor, M. S. (2008). Unmasking the pollution haven effect*. International Economic Review, 49(1):223–254.

Mansanet-Bataller, M., Chevallier, J., Hervé-Mignucci, M., and Alberola, E. (2011). EUA and CER phase II price drivers: Unveiling the reasons for the existence of the EUA–CER spread. Energy Policy, 39(3):1056–1069.

Martin, Ralf, Mirabelle Muûls, Ulrich Wagner. 2012a. *An Evidence Review of the EU ETS*. DECC. UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48449/5725-an-evidence-review-of-the-eu-emissions-trading-sys.pdf

Martin, R., Muuls, M., de Preux, L., and Wagner, U. (2012b). Industry compensation under relocation risk: A firm-level analysis of the EU emissions trading scheme. Discussion paper, Center for Economic Performance.

Martínez-Rivera, B. and Ventosa-Santaulària, D. (2012). A comment on 'Is the spurious regression problem spurious?'. Economics Letters, 115(2):229–231.

McCallum, B. T. (2010). Is the spurious regression problem spurious? Economics Letters, 107(3):321–323.

Meunier, G., Ponssard, J.-P., and Quirion, P. (2012). Carbon leakage and capacity-based allocations: is the EU right? Working Papers series 4029, CESifo Groups Munich.

Miltner, A. and Salmons, R. (2009). Trends in the competitiveness of selected industrial sectors in ETR countries. In Carbon-energy Taxation: Lessons from Europe. New York, oxford university press edition.

Neuhoff, Karsten. *Tackling Carbon. How to price carbon for climate policy*. University of Cambridge. 15/7/2009. Version 1.2

Oikonomou, V., Patel, M., and Worrell, E. (2006). Climate policy: Bucket or drainer? Energy policy, 34(18):3656–3668.

Ponssard, J.-P. and Walker, N. (2008). EU emissions trading and the cement sector: a spatial competition analysis. *Climate Policy*, 8(5):467–493.

Porter, M. E. and Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *The Journal of Economic Perspectives*, 9(4):97–118.

Quirion, P. (2011). Les quotas échangeables d'émission de gaz à effet de serre: éléments d'analyse économique. Mémoire d'HDR, Ecole des Hautes Etudes en Sciences Sociales (EHESS).

Rayner, S. (2010). How to eat an elephant: a bottom-up approach to climate policy. *Climate Policy*, 10(6):615–621.

Reinaud, J. (2008a). Climate policy and carbon leakage. impacts of the European emissions trading scheme on aluminium. IEA information paper, IEA. Reinaud, J. (2008b). Issues behind competitiveness and carbon leakage. Focus on heavy industries. IEA information paper, International Energy Agency, OECD/IEA Paris.

Sartor, O. (2013). Carbon leakage in the primary aluminium sector: What evidence after 6.5 years of the EU ETS? SSRN Scholarly Paper ID 2205516, Social Science Research Network, Rochester, NY.

Selim, T. and Salem, A. (2010). Global cement industry: Competitive and institutional dimensions. Technical Report 24464.

Smarzynska, B. K. (2002). Does foreign direct investment increase the productivity of domestic firms : in search of spillovers through backward linkages. Policy Research Working Paper Series 2923, The World Bank.

Sollis, R. (2011). Spurious regression: A higher-order problem. *Economics Letters*, 111(2):141–143.

Tobey, J. A. (1990). The effects of domestic environmental policies on patterns of world trade: An empirical test. *Kyklos*, 43(2):191–209.

Ventosa-Santaularia, D. (2012). Unbalanced regressions and spurious inference. *Open Journal of Statistics*, 02(03):297–299.

WBCSD. 2013. Getting the Numbers Right database. http://wbcsdcement.org/index.php/key-issues/climate-protection/gnr-database

WCA (2011). Coal and steel facts 2011. Technical report, World Coal Association.

WSA (2012). World steel in figures 2012. Technical Report ISSN 1379-9746, World Steel Association.

Zachman, G., Abrell, J., and Ndoye Faye, A. (2011). Assessing the impact of the EU ETS using firm level data. Technical Report 2011/08.

Zhang, L. (2013). Partial unit root and linear spurious regression: A Monte Carlo simulation study. *Economics Letters*, 118(1):189–191.

## Annex

Table 7: Augmented Dickey-Fuller tests for unit root

| | 1999-2012 | | 2004-2012 | |
|---|---|---|---|---|
| | Test Statistic | p_value | Test Statistic | p_value |
| $NImp_{Cement}$ | -2.527 | 0.1091 | -1.578 | 0.4947 |
| $\triangle NImp_{Cement}$ | -18.849 | 0.0000 | -14.275 | 0.0000 |
| $NImp_{Steel}$ | -2.881 | 0.0477 | -2.013 | 0.2807 |
| $\triangle NImp_{Steel}$ | -14.655 | 0.0000 | -11.296 | 0.0000 |
| $Ind_{EU}$ | -1.709 | 0.4266 | -1.137 | 0.6999 |
| $\triangle Ind_{EU}$ | -11.065 | 0.0000 | -7.683 | 0.0000 |
| $Ind_{BRICS}$ | 0.730 | 0.9904 | -0.636 | 0.8627 |
| $\triangle Ind_{BRICS}$ | -17.279 | 0.0000 | -13.692 | 0.0000 |
| $Cons_{EU}$ | -1.425 | 0.5702 | -0.770 | 0.8277 |
| $\triangle Cons_{EU}$ | -18.429 | 0.0000 | -14.566 | 0.0000 |
| $CO_2price$ | | | -2.094 | 0.2471 |
| $\triangle CO_2price$ | | | -8.518 | 0.0000 |

The ADF model specified is model with constant