Over-allocation profits and competition issues in the steel industry

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Abstract

Sectors that are considered to be subject to international competition under the European Emission Trading Scheme (EU-ETS) still benefit from free allocation of European Allowances (EUAs). Herein we study one of those beneficiaries: the crude steel industry. Firstly, we find it is not strongly exposed to international competition. Moreover, we find that the relevant market is concentrated and that the firm with most market power throughout 2005-2018 is the one receiving most of free EUAs capturing most of the over-allocation profits (34.87% in average). Finally, after performing a frontier analysis we find that the market leader is also the least efficient in producing crude steel and consequently the least efficient in terms of CO_2 intensity. These findings suggest the EU-ETS has failed to provide incentives for decarbonization in this sector.

Surallocation de quotas gratuits et effets sur la concurrence dans l'industrie sidérurgique européenne

Les secteurs considérés comme fortement exposés à la concurrence internationale dans le cadre du système européen d'échange de quotas d'émission (EU-ETS) bénéficient toujours d'une allocation de quotas gratuits (EUA). Nous étudions ici un des principaux secteurs bénéficiaires : la sidérurgie. A travers la mesure de l'indice de Herfindahl-Hirschman, nous constatons tout d'abord que le niveau de concentration a fortement progressé depuis 2010. que en réalité il n'est pas fortement exposé à la concurrence internationale. De plus, nos résultats montrent que l'entreprise ayant le plus de pouvoir de marché sur la période 2005-2018 est celle qui a obtenu le plus de quotas gratuits, captant la plupart des bénéfices liés à cette surallocation (34,87% en moyenne). Enfin, il apparaît que le leader du marché est le moins efficace en termes d'utilisation de ressources dans la production d'acier brut, et par conséquent le moins efficace en termes d'intensité CO_2. Ces résultats suggèrent que l'EU-ETS n'a pas réussi à fournir des incitations à la décarbonation dans ce secteur.

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1 Introduction

As the cornerstone of European climate mitigation policy, the EU-ETS has faced concerns and skepticism regarding its lack of effectiveness (Laing et al., 2013). Even though few studies have showed a positive effect in terms of CO_2e reductions [1] (Ellerman and Bunchner (2008), Ellerman et al. (2010), Egenhofer et al. (2011), Dechezlepretre et al. (2014)), a specific mechanism, the Market Stability Reserve, had to be installed as from 2019 to deal with the abundance of EUAs in the market that was leading to systematic low prices, raising concerns regarding abatement incentives (Chaton et al. (2018). Additionally, since a number of countries or regional authorities have set up their own ETS, or intend to do so (*e.g.* Australia, California, China, Mexico, New-Zealand, Quebec, South-Korea), an abundant literature has emerged. The focus has now shifted from comparing trading schemes with other environmental public policies to rather understanding the best way to make trading schemes, as the EU-ETS, more efficient.

For instance, the question about the CO_2 price determinants have raised interest among researchers, especially regarding its collapse by mid-2007 and the structural changes in the scheme (Hintermann (2010), Creti et al. (2012), Aatola et al. (2013), Koch et al. (2014), Mansanet-Bataller and Sanin (2014), Ying et al. (2017)). While energy commodities appear to be the most natural determinant, [2] policy such as mechanism design can also have a strong impact on the EU-ETS, for instance, through allocation mechanisms that are too generous with regulated firms.

One of the main benefits of using a cap-and-trade system or a tax for emission reductions, as opposed to command-and-control methods, is that they allow for an overall reduction in emissions at minimum cost. The fact that all agents face the same price for emissions (*i.e.* the price of allowances in the emission market), assures that, without other distortions, abatement is achieved with the lowest cost for society. However, the body of literature on ETS systems reflect that many distortions are present in practice, due to uncertainties in the regulatory and economic environment (*e.g.* mechanism design, national climate policies, energy prices, economic activity).

In addition to price determinants studies, part of ETS-related literature is devoted to the effect of the EU-ETS on regulated sectors' competitiveness. The extra costs induced by implementing abatement technologies or more generally by complying with climate policy requirements, could be important for firms highly exposed to international competition. After several years of existence and better data availability, a small but growing academic literature has emerged to show evidence on the effects of the EU-ETS on the regulated sectors (Martin et al., 2014). These ex-post analyses have confirmed ex-ante theoretical findings that the effects on competitiveness are moderate as long as allowances allocation is free, which has been one of the responses to deal with the EU firms highly exposed to international competition. While Wagner et al. (2014) has focused on French manufacturing firms and Jaraite and Di Maria (2016) on the Lithuanian industry, Petrick and Wagner (2014) has used firm-level data to estimate the causal effect of the EU-ETS on the regulated German manufacturing sector regarding economic criteria (employment, competitiveness) as well as CO_2 emissions. Similarly, in their ex-post econometric study Abrell et al. (2011) did not find a significant negative effect of the program on the competitiveness of a panel of European firms, at least for Phase I and the beginning of Phase II.

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[1] The e in CO_2e stands for equivalent. This term stands for the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas (GHG).

[2] The electricity sector is responsible for approximately 39 per cent of European CO_2e emissions.

A similar result was found by Cludius et al. (2020) that find significant cost pass-through of EU-ETS prices in the cement, iron and steel industries. These papers have analyzed the issue for several sectors at a time, but impacts could be different among sectors, at least in magnitude.

Few papers have focused instead on the impact of the EU-ETS in the prices practiced in a single sector. Alexeeva-Talebl (2011) dwelt on the EU petroleum market through a cross-country analysis finding that EUA prices have been passed through to petrol prices. Fabra and Reguant (2014) used micro-level data for the Spanish electricity market to show pass-through of emissions costs to electricity prices. Similarly, Sijm et al. (2006) found evidence of pass-through to electricity prices by comparing a situation with and without the policy. Schaefer et al. (2010) and Ye et al. (2016) studied the aviation sector. The former found that European network carriers are affected by a competitive disadvantage compared to non-EU airlines while the latter, who studied the aviation sector after their inclusion in the EU-ETS, found that most airlines' efficiencies have increased following their inclusion. With the objective of studying leakage in the cement sector Branger (2015b) find that producers strategically adjusted output to obtain more free allocations. Our results will be close to Venmans (2016) that shows, for the ceramic industry, that over-allocation of permits refrained managers from including carbon gains in payback times and with Dechezleprêtre et al. (2018) that shows that the EU-ETS has led to an increase in regulated firms' revenues and that the negative competitiveness has been overplayed.

In this paper we contribute to the previous literature from a different perspective. We perform an in-depth economic analysis of the interaction between the EU-ETS, the CO_2 emission intensity of firms and the market structure, in particular during the transition to Phase III. To the best of our knowledge, only few papers have analyzed empirically competition between firms in a single sector and its interaction with the ETS since it requires firm-level data that is difficult to access.

We focus on the crude steel industry since it is one of the most polluting sectors and, most importantly, it is the sector that receives the most important amount of free allowance allocations in the EU-ETS. Few papers have studied this sector in the past. Okereke and McDaniels (2012) conducted a qualitative assessment showing that steelmakers exaggerated their vulnerability to carbon pricing while Demailly and Quirion (2008) and Chan et al. (2013) found evidence that the sector's international competitiveness was not affected by the EU-ETS. According to the former, "the tightening environmental stringency of the ETS in the second period should not be opposed on grounds of competitiveness losses". However, they took the sector as perfectly homogeneous and used aggregate data while, according to Reinaud (2008), "costs estimates for aggregate industry hide considerable intra-sector variations, which in turn impacts on leakage estimations". Regarding the latter, the empirical estimation did not distinguish crude steel made through iron ore from steel made from recycled materials while the industrial processes as well as the relevant market differ a lot (and are therefore subject to a different treatment within the ETS).

In this paper we consider the specific characteristics of the crude steel sector to determine to which extent it is subject to international competition and merits the allocation of free allowances, its competitive market structure as well as the interaction that these elements have had with the EU-ETS and to which extent it has led to an improvement in CO_2 efficiency. With this purpose we first define the relevant market for the crude steel and measure market power as well as concentration in that market. The justification for free allowance allocation is the exposure to international competition to protect European industry. Our main finding in this regard is that the international competition exposure of the crude steel industry is very thin, putting in question the need for free allowances in the first place. We also find that the market is concentrated with market leaders holding an important degree of market power. Moreover, we find that the current allocation method of those allowances provokes important over-allocations (OA), that are particularly large for firms with most market power. We then compare this allocation method with two alternative methods finding that they would be better than the current system, which is planned to continue at least until 2025.[3]

With the purpose to understand the CO_2 intensity of these firms and to which extent the EU-ETS has led to a decrease of such intensity as well as an improvement in overall efficiency we perform a non-parametric frontier analysis. With this purpose we first follow the approach in Cooper et al. (2007) and Charnes et al. (1978) with the distinctive characteristic that, as in Chung et al. (1997), we solve the problem considering a good and a bad output: flat steel and CO_2e emissions. Secondly, we study whether there has been a shift in terms of efficiency between the beginning of the ETS and the latest year available both in terms of input usage and emission intensity (see Alvarez et al. (2016)). We find that, unlike what is expected in theory, market leaders are not the most efficient (neither in the usage of inputs nor in terms of CO_2e intensity) and that they have not significantly improved their efficiency with time, suggesting not a lot of effort has been put into emission mitigation.

2 The steel-making industry and its interaction with the EU-ETS

Globally the iron and steel industry accounts for about 7% of anthropogenic CO_2e emissions. When the mining and transportation of iron and steel are included in the calculation, the share may be as high as 10%. European steelmakers were incorporated in the EU-ETS as from 2005. In relation to the CO_2e emissions covered by the EU-ETS, crude steel also represents between 6 and 7% all emissions.

Additionally, the sector is an essential part of the European economy: crude steel is closely linked to important downstream industrial sectors such as automobile, construction, electronics, mechanical and electrical engineering. In 2009, the total sales of the steel sector amounted to 170 billions of euros, accounting for 1.4% of the GDP of the EU-27 Member States. The EU is the second largest producer of steel in the world, with an output of over 177 million tons of steel a year, accounting for 11% of the steel global output. In addition, the sector accounts for the highest share of CO_2e emissions when considering only the manufacturing sector, about 27% (International Energy Agency, 2007).

In Subsection 2.1. we describe the database on the installations included in this study as well as the aggregation we conduct to use firm-level data. In Subsection 2.2. we analyze how allowances were allocated to these installations, which in turn constitutes firm-level

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[3] The "Fit for 55 package" released by the European Commission (EC) in July 2021 includes a revision of the EU-ETS rules to make it more effective, as well as a proposal for a Carbon Border Adjustment Mechanism (CBAM) to address the carbon leakage issue. According to the European Commission, carbon leakage "refers to the situation that, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints"(EC, 2018).

over-allocation profits.

2.1 Installation and Firm-level Data

We use an original database with 28 steel-making installations representing 92% of EU production over 13 years (on average from 2005 to 2018). We compile the observations about crude steel production and CO_2e emissions coming from the annual report of each of the firms, disentangling coke, sinter, and BOF. We then cross check the resulting data with the 2018 World Steel Statistics Yearbook. We also collect Information on the technology from the German Federation of steel and cross-check the results. Regarding CO_2e emissions, we matched the data on installations just mentioned with the European Union Transaction Log (EUTL) for the same period, from which we also extract allowances allocations that are discussed in the next section. These are also crosschecked with the European Pollutant Release and Transfer Registry (E-PRTR) and the database from Branger (2015a).

Most of CO_2e emissions in this industry result from the production of crude steel production based on the BOF process.[4] The BOF process differs from the secondary production, *i.e.* recycled steel, that is based on Electric Arc Furnaces (henceforth the EAF process). This is the case because EAF does not use iron ore and coking coke as inputs, which produce most of CO_2e emissions. As a result of the BOF process flat steel is produced, used as an input for the automobile and mechanical industry as well as rapping material. This differs from the long steel resulting from EAF that is used in the construction industry. CO_2e emissions coming from the production of recycled steel using EAF is marginal compared to the emissions resulting from BOF and cost structures are very different in both processes. Also, the relevant market for those products differs: while ferrous scrap is mostly exported, crude steel coming from the BOF process stays almost exclusively in Europe. In this paper we therefore concentrate on the crude steel resulting from the BOF process only.

Result *Crude steel industry in the European Union is not strongly exposed to international competition.*

The previous result derives from the fact that the relevant market for crude steel produced from installations in our database is concentrated in Europe. Table 1 shows that only 15% of crude steel is imported and the same happens with exports.

Another precision is in line: steel-making installations are sometimes connected to a power plant, usually owned by a power provider, that recovers gases from each operation and produces electricity to sell to the grid and to support the small amount of electricity needed in the steel-making installation (Pardo and Moya (2013)). The emissions reduced by recycling those emissions to produce electricity are accounted for the power plant and

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[4] In a nutshell, the production of crude steel in an integrated steel-making installation requires three preceding processes namely coke making (NACE code Rev.2: 19.10), sintering (NACE code Rev.2: 07.10) and iron making (NACE code Rev.2: 24.10). The former is the conversion of metallurgic coal to coke, while the second one consists of agglomerating different grain sizes of iron ore with additives to form an intermediate material. The coke as reducing agent and the sintered ore (*i.e.* agglomerated iron ore) are then feed into a blast furnace to produce liquid iron which is called hot metal. Finally, the last step takes place in a BOF to remove unwanted elements and as much of the residual carbon as possible in order to convert the metal into crude steel of the required quality. Each operation is performed in different units of the crude steel-making installation.

Table 1: Relevant market for the EU crude steel industry

	Total consumption of flat products in EU Market Mt	Consumption of flat products satisfied by imports from outside the EU, Mt	Import percentage	Total production of flat products in EU Market Mt	Production of flat products exported out of EU, Mt	Export percentage
2005	94.6	10	10.6%	103	18.5	17.9%
2006	110.1	17	15.2%	111	17.2	15.6%
2007	114.1	22	19.0%	109	17.0	15.5%
2008	107	18	16.9%	103	14.1	13.7%
2009	70	9	13.0%	73	11.9	16.3%
2010	88.5	12	13.3%	94	16.9	18.1%
2011	94.3	15	16.0%	96	16.7	17.4%
2012	85.8	10	12.1%	91	15.4	17.0%
2013	87.4	12	13.3%	91	14.8	16.3%
2014	90.1	13	14.9%	93	16.5	17.7%
2015	94.4	17	17.9%	92	14.6	15.9%
2016	97.9	19	19.4%	92	12.6	13.8%
2017	98.5	19	19.5%	95	15.6	16.4%
2018	99.7	20	20.1%	95	15.0	15.9%
Average			15.8%			16.2%

Sources: Own elaboration based on Worldsteel (2019) and Eurofer (2020).

not for the steel installation (EC (2018)), so we have no interest to consider them herein. [5] We have excluded from our dataset the installations for which we were unable to disentangle data from the steel plant from the power plant (e.g Teeside steelworks in the UK). Moreover, in the perimeter of each flat steel installation, we have considered the fact that all of them are composed of a coke plant, a sintering plant and one or several ovens as well as one or several converters. We have excluded the installations for which we were unable to verify the presence of coking and sintering plants (e.g. Evraz Viktovice steel in Czech Republic). All in all, we have excluded due to data availability the following plants: Voestalpine Donawitz (Austria), ArcelorMittal Eisenhuttenstadt (Germany), FN Steel Lappohja (Finland), Evraz Viktovice (Czech Republic), Severstal Piombino (Italy), Teeside steelworks (UK).

On average, the share of the coking plant in total crude steel emissions is 9.1% while for the sinter plant the share is 12.7% (Ecofys, 2009). The most CO_2e intensive part of the process refers to the two other steps covering the hot metal and crude steel production with approximately 69.3%.[6] The rest of the emissions are related to the downstream process (*i.e.* hot and cold rolled steel). [7]

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[5] Regarding the potential substitution of thermal energy with electricity, such potential is very thin: 4.6kWh/steel-tons is required of thermal energy compared to 0.415kWh/steel-tons for electricity.

[6] These figures are indications from 2005-2008. They should be considered cautiously since they are "extremely sensitive to small changes in the raw data and the raw data itself is prone to high uncertainties" (Ecofys, 2009).

[7] The crude steel industry has the following options to reduce emissions: (i) improve energy efficiency of the production process of steel itself, which according to Pardo and Moya (2013), allows firms to decrease their CO_2e intensity by 0,26 tCO_2e/t; (ii) the use of iron ore pellets as a substitute to sintered ore, which could decrease emissions by 14%; and, (iii) replacing up to 25% the use of hot metal in the Blast Oxygen Furnaces process (henceforth the BOF process) with the use of ferrous scrap, which represents the greatest potential for emission reduction and efficiency.For instance, Voestalpine-Linz, which is one of the most efficient installations, used 0,276 tons of scrap per ton of crude steel in 2019 (Voestalpine (2020)) The physical drivers of the heterogeneity of CO_2e intensity among installations are

We compute the CO_2e emission intensity for each installation i in time t, as:

$$EI_{i,t} = \frac{Emissions_{i,t}}{Crude\ steel\ output_{i,t}}$$

.

The results for each Phase are presented in Table 2 as well as their standard deviations.

Table 2: CO_2e emission intensities of the EU crude steel-making installations

	Mean				Standard Deviation		
	All phases	Phase I (2005-2007)	Phase II (2008-2012)	Phase III (2013-2018)	P1	P2	P3
All installations	1.31	1.35	1.43	1.30	0.44	0.51	0.43
The 5 most efficient	0.90	0.87	0.92	0.88	0.08	0.05	0.05
The 5 least efficient	2.1	2.1	2.2	2	0.12	0.26	0.26

Sources: Firm's annual reports, Worldsteel (2019) and EU-ETS database.

Over the period 2005-2018, the 5 most efficient installations represented on average 23% of the crude steel produced, and the least efficient represented 16% of the market. Numbers in Table 2 show a very low variation in the CO_2e intensity in the steel industry over time but a strong gap in CO_2e intensity between the most and less efficient installations. These differences remain even after the publication of the "BREF" report,[8] which encompasses technologies to help steelmakers reduce their emissions. The heterogeneity among installations is stronger among those less efficient, compared to the most efficient ones. Additionally, the ranking is quite stable: the three most CO_2e efficient installations are Lulea (SSAB), Ghent (ArcelorMittal) and Linz (Voestalpine) throughout the period, while the least efficient are Scunthorpe (Tata Steel), Galati (ArcelorMittal) and Fos-sur-Mer (ArcelorMittal).

Using the absolute values of CO_2e emissions and output, we have added up installation data at the firm level. We have then merged and compared this with data collected on iron ore and coking coal consumption per firm. This data comes from the 2016 Worldsteel Association Yearbook and from the International Energy Agency (IEA). Summary statistics of these results appear in Table 3. In what follows, we first present EUA´s allocation rules to installations and then we concentrate on this firm-level data since we are mostly interested in the interaction between the EU-ETS and competition in the crude steel sector.

2.2 Allocation of allowances in the EU-ETS

The cap for Phase I and Phase II discriminated in terms of reduction efforts among countries in what was called the National Allocation Plans (NAPs). As from Phase III starting in 2013, an European-wide cap on emissions was decided corresponding to a reduction

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therefore a number of energy efficiency determinants such as the presence of a combined heat and power solution, or implementing the previously mentioned innovations (Worell et al. (2001), Siitonen et al. (2010)).

[8] The BREF report is the Best Available Techniques (BAT) Reference Document for Iron and Steel Production adopted within the IPPC Directive (2008/1/EC) and the IED Directive (2010/75/EU) for several industrial sectors.

Table 3: Summary statistics

	2007				2018			
	Mean	Med.	Min.	Max.	Mean	Med.	Min.	Max.
Output ('000 tons)	8,659	5,363	918	39,783	7,536	4,706	16,569	33,600
CO_2e Emissions ('000 tons)	11,885	5,593	1,156	63,966	9,455	5,899	1,278	42,110
CO_2e intensity	1.27	1.24	0.93	2.06	1.19	1.24	0.7	1.63
Nbr of free EUAs (thousands)	13,790	6,374	2,141	83,257	11,859	6,739	1,919	48,557
Free EUAs per ton of CO_2	1.19	1.08	0.85	1.85	1.28	1.24	0.92	2.00
Iron ore cons. ('000 tons)	12,718	8,514	2,085	55,516	10,520	7,148	1,968	46,925
Coking coal cons. ('000 tons)	4,566	2,448	929	22,072	3,930	2,164	784	17,443
Number of firms (installations)	14(28)				12(25)			
Average price of EUAs (Euros)	0.7				16			

Sources: Own elaboration based on firm's annual reports, the EU-ETS database, Worldsteel (2019) and IEA data.

of 21% as compared to 2005 levels (*e.g.* in July 2010, in its Decision 2010/384/EU, the European Commission determined the cap from 2013 onward).

Regarding the allocation rule during Phase I, about 97% of EUAs were distributed for free to regulated installations, and 90% for Phase II.[9] In Phase III roughly half of the allowances are distributed through an auction while sectors considered to be subject to international competition, like the steel sector, continue to receive free allowances. The way those allowances are allocated has changed over time. During Phase I and Phase II Historical-Based Allocation (HBA) was used, meaning that firms received allowances according to their historical emissions. Some studies have underlined the flaws of the HBA allocation rules (*e.g.* Betz et al. (2006); Anderson and Di Maria (2011); Sartor et al. (2014)). The main flaw is that HBA rewards the higher CO_2 intensive installations with more permits, disregarding early mitigation efforts.[10]

In order to address the flaws in permit allocations during Phase I and Phase II, the European Commission switched into what Sartor et al. (2014) and others called Benchmark-Based Allocation (BBA).[11] As explained by Branger (2015b), this system combines an *ex-ante* calculation of an allocation based on historical output, and an emission intensity benchmark. An adjustment can also be made according to capacity extension or reduction, plant closure and/or the arrival of new entrants. The number of allowances per year to each installation receiving free allocations, is:

$$FA_{i,p,t} = BM_p \times HAL_{i,p} \times CLEF_{p,t} \times CSCF_t \tag{1}$$

where $FA_{i,p,t}$ is the free allocation granted to i for its product p in time t; HAL is the historical activity level; $CLEF$ is an allocation reduction factor applied to installations considered not to be at risk of carbon leakage; $CSCF$ is a uniform cross-sectoral correction factor that can be applied to ensure that the total free allocation will not exceed the maximum annual amount of free allocation; and BM is the emissions-intensity benchmark of output or "product" p. Since the crude steel sector is considered at risk of carbon leakage, coefficient $CLEF = 1$ for all years. The coefficient $CSCF_t$ captures the yearly

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[9] Phase I allowances could not be banked for use in Phase II. Instead, Phase II allowances can be used during Phase III

[10] Also, it is now well documented that the EU-ETS has been oversupplied in allowances, especially after the 2008 economic crisis, one of the main reasons to implement the MSR (Chaton et al. (2018)).

[11] This was called by others like Meunier et al. (2014) Capacity Based Allocation.

reduction needed to respect the 21% reduction in the cap.[12] The HAL value refers to the median annual production level from 2005-2008 for all installations.

An alternative mechanism called Output-Based Allocation (OBA) has been studied by Quirion (2009). In such a system, allocations per installation at t are based on the activity at $t-1$ after applying the yearly reduction of the global cap in $CSCF_t$. Comparing Historical-Based Allocation (HBA) and Output-Based Allocation (OBA), Quirion (2009) explained that, under HBA, a rational profit-maximising firm includes the anticipated value of emissions per unit produced in its marginal cost, that in a competitive market pushes the firm to reduce its output. We will see herein that in the case of the steel industry no reduction of output has been observed. Instead, in an alternative OBA the installation would include the value of the additional allowances received for each unit produced in its marginal revenue.

The level of the BM is of particular interest since this determines the stringency of the EU-ETS for the sector. For other industrial sectors, a harmonised BM is used, that is basically the average performance of the 10% most efficient installations in each sector between the years 2007-2008. For the steel-making sector the rule is different: according to Decision 2011/278/EU (Art.11), "in particular, due to a lack of data, the values for the product benchmarks for coke and hot metal have been derived from calculations of direct and indirect emissions based on relevant energy flows provided by the relevant BREF." Hence, according to available data and after consultations with stakeholders, the BM for the crude steel sector has been set up as follows:

$$\begin{aligned} BM_{coke} &= 0.286\,EUA \\ BM_{sinter} &= 0.171\,EUA \\ BM_{hot\ metal} &= 1.328\,EUA \end{aligned}$$

According to the BREF report, to produce one tonne of crude steel, on average, 1.08 tonnes of iron ore and 0.359 tonnes of coke are required. These figures led us to consider that the BM for crude steel production is equal to:

$$BM_{crude\ steel} = BM_{coke} \times coke\,ratio + BM_{sinter} \times iron\,ore\,ratio + BM_{hot\ metal} \tag{2}$$

$$BM_{crude\ steel} = 0.286 \times 0.359 + 0.171 \times 1.08 + 1.328 \tag{3}$$

$$BM_{crude\ steel} = 1.616 \tag{4}$$

Taking into account the four step process, the integrated steelmakers having an emission intensity equal to 1.616t of CO_2e per tonne of crude steel, receive enough allowances to fully cover their emissions for a year. Instead, if we compute an hypothetical benchmark based on the rule used for other regulated sectors, that is considering the 10% most efficient installations, we would have a: $\widehat{BM}_{crude\ steel} = 0.841$. This is less than twice the value of the BM used to allocate the level of current allowances in the steel-making industry.

Figure 1 shows the percentage of CO_2e emissions that are covered with free allowances for the industry in three alternative scenarios for Phase III (from 2013 on). First, the percentage covered when the allocation is done using the current way of calculating the BM for the steel industry. Second, the percentage that would be covered if the free

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[12] The coefficient $CSCF_t$ takes the following values 0.942721, 0.926347, 0.909780, 0.89304105, 0.87612124, 0.85903685 respectively for the years 2013, 2014, 2015, 2016, 2017, 2018 (Commission Decision 2013/448/EU) to capture the yearly reduction needed to respect the 21% reduction in the cap.

allowances had been distributed using the same rule that is used for other sectors, namely, $\widehat{BM}_{crude\ steel} = 0.841$. Finally, the percentage that would be covered if OBA was used instead. Regarding the calculation, we have applied (1) for the first two alternatives that use a BM and for OBA we used the method explained, using the coefficient $CSCF_t$ to capture the cap reduction. A rate of over 200% means they have received more than twice the number of allowances required to comply with the EU-ETS rules. Conversely, for instance, an 70% rate means that installations must buy 30% of allowances.

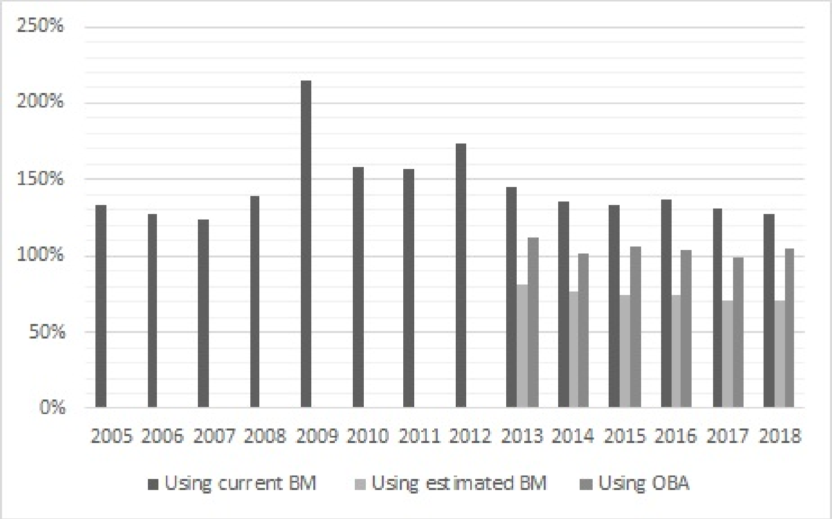

Figure 1: Percentage of emissions covered with free allowances under alternative allocation rules

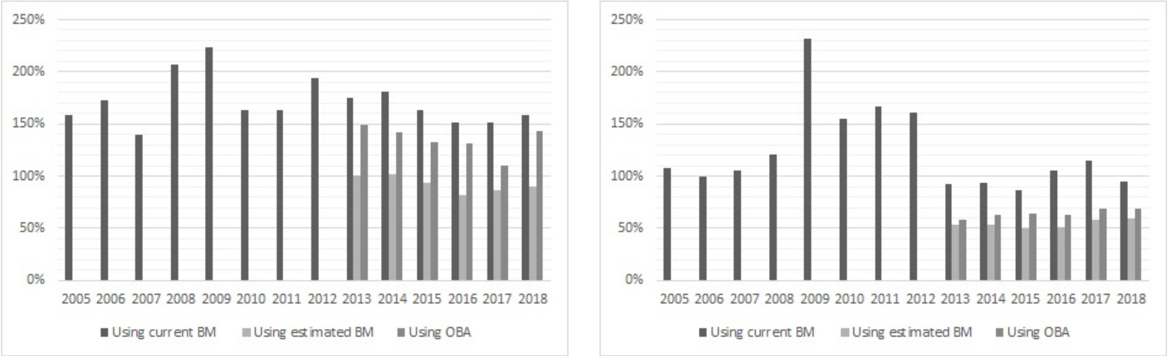

Figure 2: Percentage of emissions covered with free allowances under alternative allocation rules for the most (least) efficient installations in the left (right).

Firstly, regarding the period of Phase II from 2007-2012, we observe in Figure 1 the effect of the 2008 crisis, that hit particularly during 2009, reducing production of 35% as compared to the median level since 2007. Such decrease resulted in a decrease in CO$_2$e emissions and, since allowances were allocated according to historical emissions, the oversupply was very important. This oversupply feature is well documented in the literature and has lasted throughout Phase II and Phase III.

Focusing on Phase III (2013 on), in Figure we observe differences are significant among installations. While some still benefit from a large over-allocation with the current benchmark (*i.e.* twice the level of EUAs required to fully cover their emissions), it seems that adopting alternative rules (like the $\widehat{BM}_{crude\ steel}$ we suggest or OBA) for Phase III would imply that the less efficient installations would become buyers of allowances for a slight proportion (assuming they choose to cover emissions through the market instead of reducing their emission intensity). As expected, using $\widehat{BM}_{crude\ steel}$ makes compliance with EU ETS more stringent. In addition, differences with OBA does not seem to be significant except in 2018 and for the most efficient firms which would sill benefit from a generous over-allocation under a benchmark scheme as compared to OBA.

Result *Allocation of EUAs have greatly exceeded installations' needs across the whole period. Any alternative allocation method would have resulted in less allowances' surplus.*

In Phase IV (2021-2030) the steel industry will continue to receive free EUAs based on historical output, and the conditions for these free allocations will be more advantageous than for other sectors. The reference level of emissions will be calculated considering the average of 2013-2017 for the 2021-2025 period, and the average of 2018-2022 for the 2026-2030 period, while for other sectors the period 2016-2017 is considered already for allocations in 2018-2022 (Directive EU 2018/410). Regarding the benchmark value BM, the coefficient will be updated yearly by a 0.2% until the end of Phase IV, while for other sectors the decrease is higher, ranging from 0.2% to 1.6%. [13]

To analyse the interaction between the EU-ETS and competition in the crude steel sector in the following section we turn to the firm-level database that we have built, as explained in Section 2.1, by aggregating installation data considering their ownership.

3 Market share and over-allocation profits

In Table 1 we have shown that the relevant market for crude steel production is the EU. Since it is a market on its own, we can calculate the market shares per firm (in Table 4) as well as the market concentration and market power (in Table 5). We observe that the production of crude steel is dominated by a leader representing more than 33% of the market with two other firms following, on average, with 14% of the market each. The rest of the supply is provided by steelmakers who serve on average between 7% and 1% of the market. Besides, we do not observe significant variations in the market shares with time. Moreover, in Table 5 we show that the HHI has increased up to reaching an important concentration, well above the level of 1500.[14] We also show that the Lerner Index (LI) of the market leader, ArcelorMittal, is 20 times higher than the LI of smaller firms and almost 3 times higher than its closest follower.

Based on the free allocations discussed in the previous section, the steel industry benefits from important over-allocation (OA) profits. According to Branger (2015a), "over-allocation profits can be distinguished from windfall profits, which refer to the profits from free allocation where emitters additionally profit from passing on the marginal CO_2 opportunity cost to product prices, despite receiving the allowances for free. Over-allocation profits can occur even in the absence of cost pass through, for example, if output falls short of historical levels." Figure 3, shows the price gap between a ton of steel and

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[13] The CSCF will now reflect the decreasing cap of -55% of emissions at 2030 and allocations will be phased-out in accordance with the rhythm of implementation of the Carbon Border Adjustment Mechanism (CBAM) which is expected no earlier than in 2032.

[14] A level of HHI higher than 1500 is interpreted as an indication of market concentration.

Table 4: Market shares per Phase in crude steel

	Phase I (2005-2007)	Phase II (2008-2012)	Phase III (2013-2018)
ArcelorMittal	—	33.1%	35.1%
Mittal	19.7%	—	—
Arcelor	13.6%	—	—
ThyssenKrupp	15.7%	14.8%	13.2%
Tata Steel	13.2%	13.6%	13.7%
Ilva	8.1%	7.4%	5.5%
Voestalpine	4.7%	5.6%	5.8%
SSAB	3.5%	3.6%	5.9%
Rautaruukki	2.5%	2.0%	0.0%
Salzgitter AG	5.6%	6.3%	6.4%
US Steel	4.2%	4.4%	4.8%
Dillinger Hütte	2.1%	2.5%	2.5%
Moravia Steel	2.3%	2.7%	2.8%
Saarstahl	2.5%	2.3%	2.9%
ISD Dunafer	1.5%	1.7%	1.4%
Carsid Duferco	0.9%	0.0%	0.0%

Sources: Own elaboration based on firm's annual reports and Worldsteel (2019).

Table 5: Lerner Index per firm and yearly Herfindahl-Hirschman index

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
ArcelorMittal			470	457	442	436	436	436	452	457	461	458	483	495
Mittal	150	167	Acquisition of Arcelor											
Arcelor	273	272	by Mittal in 2007											
ThyssenKrupp	243	195	189	194	190	216	197	189	181	172	179	186	170	167
Tata Steel	174	176	178	180	200	176	174	177	205	196	194	187	157	158
Ilva	109	112	103	107	82	91	106	104	75	80	69	81	68	67
Voestalpine	60	64	64	69	74	74	75	79	83	79	78	76	84	68
SSAB	49	46	45	47	36	48	43	68	74	78	77	83	83	82
Rautaruukki	34	36	30	33	36	32	32	Acquisition by SSAB in 2012						
Salzgitter AG	71	77	74	76	79	83	88	92	88	88	81	80	85	88
US Steel	51	60	56	53	67	60	55	60	61	61	61	64	67	71
Dillinger Hütte	27	28	31	34	36	30	36	34	30	33	35	32	37	34
Moravia Steel	28	32	30	32	42	35	35	37	38	36	37	37	36	38
Saarstahl	32	34	33	32	25	29	34	34	37	38	40	35	40	41
ISD Dunafer	20	21	21	20	24	22	22	22	11	14	22	15	23	24
Carsid Duferco	12	13	11	Shut down in 2007										
Market's HHI	659	591	1646	1602	1520	1546	1518	1525	1572	1589	1603	1609	1707	1758

Sources: Own elaboration based on firm's annual reports and Worldsteel (2019) for crude steel production, using price elasticity equal to -0,075 estimated by Fernandez (2018).

an EUA.[15] To fully appreciate this gap consider that a ton of crude steel produces 1,31 tons of CO_2e (average in 2005-2018). If, just for reference, we consider that ratio and write the cost of CO_2e included in a ton of steel (0,76*EUAprice) we observe that the incentive to reduce emissions by reducing output is very slim. Additionally, we do not have evidence on whether market leaders were able to sell permits at their highest price

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[15] During Phase I (2005-2007) flat product's prices increased 170%. This is due to a great increase in demand. Concentration in the market was lower but increasing already. During that period EUA permits could be sold with positive prices until the first quarter of 2007.

or other strategical maneuvers they could have performed to create additional profits, consequently in this paper we only consider OA-benefits and not windfall profits.

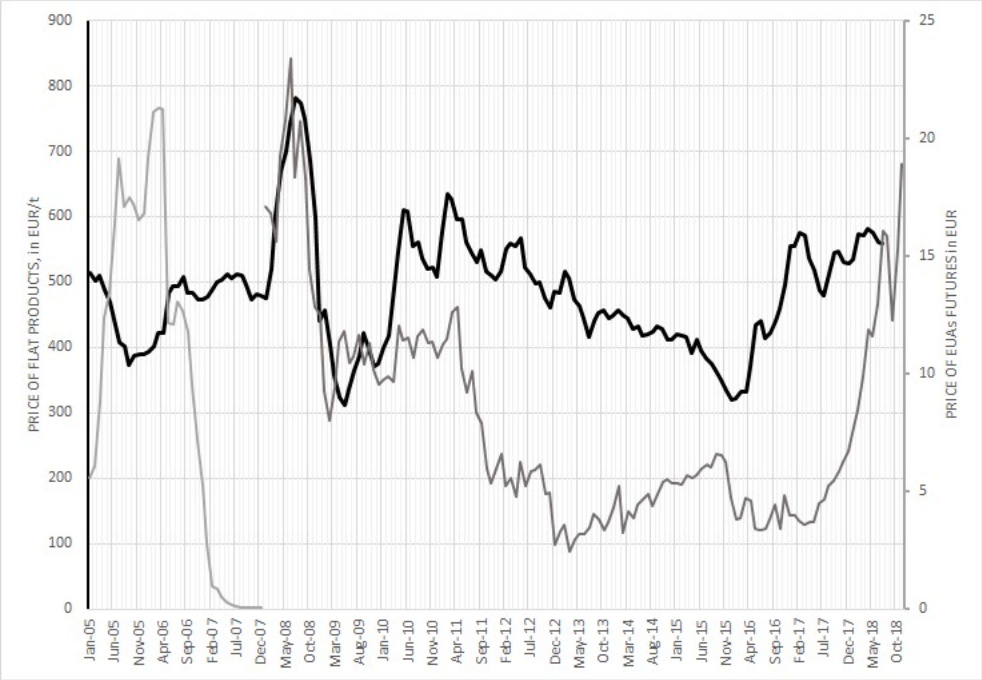

Figure 3: Comparison of crude steel and EUA prices using OECD (2021) based on Platt's (2019) and Quandl (2018) for flat products price and Agency (2011) for EUA prices

OA-benefits can be computed for each firm with the excess of allowances and the EUA average price per Phase. Figure 4 shows this OA-profits, accumulated throughout the period.

We observe that OA-profits are very different between firms. With € 5,385 million (Euros 2015), the leader has almost twice the over-allocation profits of the second steelmaker (€ 2,761 million), and it represents three times more than the third one (€ 1,359 million). Regarding the top five steelmakers benefiting from the EU-ETS, our results are in line with what Sandbag (2011) observed before 2011 and what he called the "Fat Cats".[16] In the Figure we distinguish OA-profits from Phase I from the ones from the subsequent phases since permits in that phase could not be banked.

To better reflect the heterogeneity regarding OA-profits, Table 6 presents the firms' share of the total OA-profits per Phase.

For Phase I, results show that ArcelorMittal captured more than half of the total OA-profits while the negative values show that the EU-ETS was slightly costly for a few firms in the sense that they had to buy permits. A redistribution of OA-profits occurs in Phase II, to the detriment of the leader but favoring the next two in line. This trend is also observed in Phase III, favoring the next three in line in this case.

Finally, by computing the average OA-profits that would result for Phase III using the alternative $\widehat{BM}$ value we proposed, Figure 5 shows the firms that benefit the most

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[16] Our estimations slightly differ in three points. Firstly, we use a different period so we consider different installations. Secondly, the price is also different: Sandbag (2011) used a constant value of € 17 (06/05/2011) over the period 2008-2010 while we use the average price of each Phase. Thirdly, herein we focus on the BOF process only while Sandbag´s database includes both the EAF process and the downstream sector, representing a difference of only 19% of emissions covered for 2005-2018.

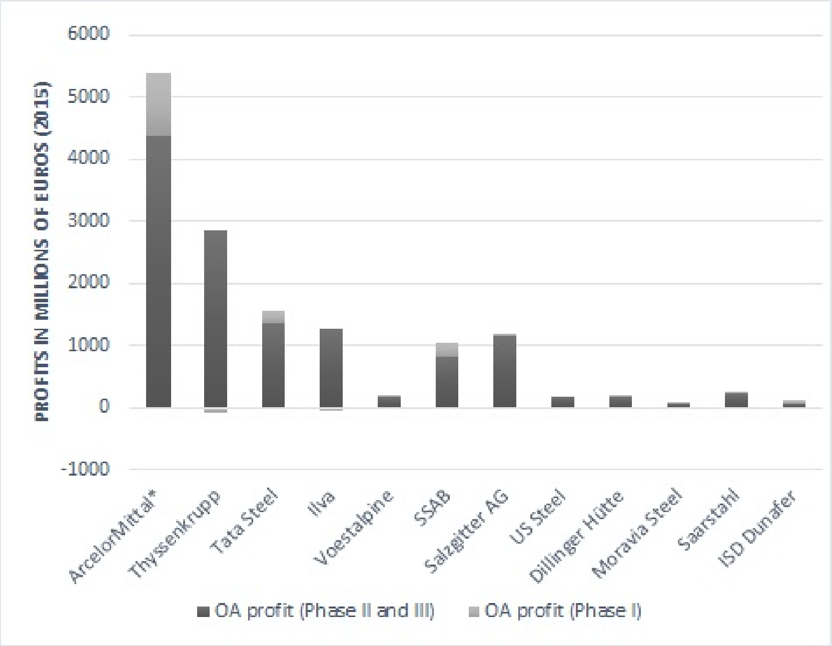

Figure 4: Accumulated OA-profit from 2005 to 2018 (in absolute terms)

Table 6: Average part of total OA-profits per Phase

	Phase I (2005-2007)	Phase II (2008-2012)	Phase III (2013-2018)	Average
Arcelor Mittal	55.04%	36.52%	23.41%	34.87%
ThyssenKrupp	-6.95%	22.81%	24.11%	16.99%
Tata Steel	16.99%	10.98%	10.47%	12.05%
Ilva	-4.70%	5.30%	27.07%	12.49%
Voestalpine	3.89%	0.84%	3.40%	2.59%
SSAB	19.46%	6.76%	3.82%	8.22%
Salzgitter AG	0.16%	10.80%	4.17%	5.68%
US Steel	-0.36%	2.36%	-2.14%	-0.15%
Dillinger Hütte	1.34%	1.48%	0.20%	0.90%
Moravia Steel	0.20%	0.02%	2.79%	1.24%
Saarstahl	2.05%	2.03%	0.59%	1.42%
ISD Dunafer	4.78%	0.01%	2.10%	1.93%
Carsid Duferco	8.10%	0.10%	0.00%	1.77%

Note: Profits are calculated using the average price for each phase.

from the current allocation method. The wider the gap between the black and the grey bar, the more a firm profits from the fact that a less restrictive benchmark BM is used for the steel industry as compared to the other sectors as in $\widehat{BM}$.

With the current allocation method, free allowances benefit the most firms with higher market shares, which we showed (Table 5) that hold most market power. Consequently, this benefit is likely to strengthen their position as market leaders. Indeed we observe that market shares have remained constant after the big acquisition of Arcelor by Mittal (see Table 4), that LIs (see Table 5) have been stable and that the HHI has slightly increased over the period. Moreover, there is a strong and significant correlation between market power and OA-profits, with a Pearson correlation coefficient close to 1 in the case of Phase II and Phase III (see detailed Table in Appendix).

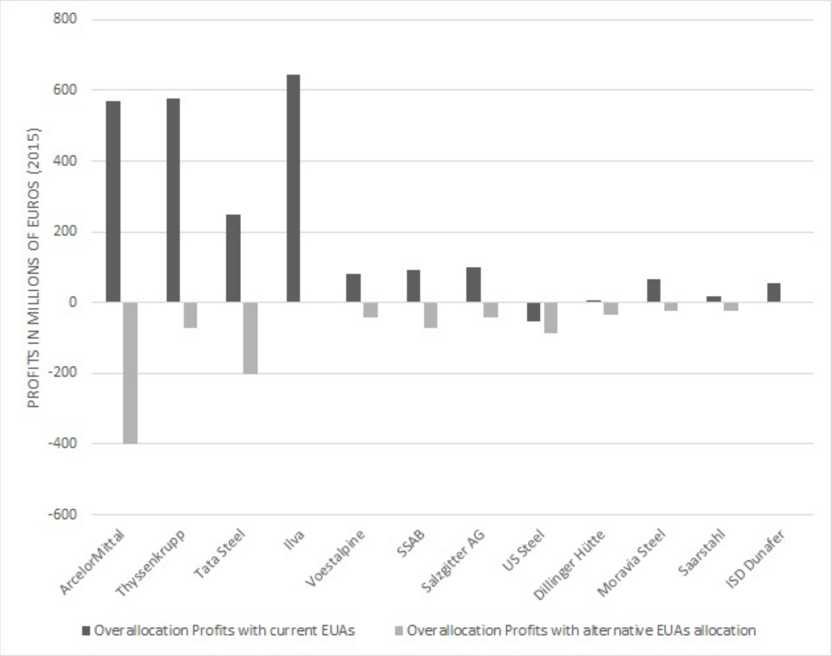

Figure 5: OA-profits in 2013-2018 with the current BM compared to $\widehat{BM}$

Result *Surplus of EUA allocations have resulted in important OA-profits. Firms with most market power have profited the most from these OA-profits. Market power and OA-profits are strongly correlated with a Pearson coefficient close to 1.*

In summary, the evidence provided underlines several design errors in the way the crude steel industry has been considered by the European Commission regarding the EU-ETS regulation. The main reason for a sector to be eligible to get free allowances is exposure to international competition, since pass-through of the EUA cost would mean losing competitiveness as compared to producers not subject to a carbon price. In Table 1 we have shown that international competition is not an issue for the crude steel industry, suggesting the sector should not receive free allowances in the first place. But this is not all: the relevant market, which is inside the EU, is in itself concentrated and those free allocations are benefiting the firms with most market power. Since those free allocations are, at least partially, depending on historical production, they may indeed help consolidate the dominant position of market leaders.

Moreover, regarding the allowance allocation method, we have shown that the crude steel sector gets more permits than other sectors due to a very generous way of calculating the benchmark BM, which aggravates the previous design problem.

The previous findings suggest that OA-profits is probably helping firms to consolidate their market power. Since allowances are free, firms can at the same time pass-through the cost of EUAs to prices and sell those unused EUAs in the EU-ETS.

Some argue that OA-profits could be due to bad design but it could also be the result of important mitigation efforts, either due to a decrease in production itself, or to the implementation of new technologies (see Ellerman and Bunchner (2008)). We have shown that production quantities did not decrease following changes in EUA prices. We must now rule out the mitigation explanation where OA-profits result from the implementation of new technologies that decrease emission intensities (even if we already suspect that this is not the case due to the stable coefficients we showed in Table 2). To understand if these firms benefited from high OA-profits due to an improvement in their carbon efficiency (and in their efficiency in general), which would be a testimony of the EU-ETS giving the right incentives despite the issues just mentioned, in the following section we perform a Data Envelopment Analysis (DEA).

4 Methodology for a DEA-based environmental performance evaluation

Unlike the standard DEA models, herein we integrate the environmental externality as an undesirable output. Then we use a Directional Distance Function technique representing the distance between observed and efficient fictive values. This DEA model allows us to estimate how much firm's efficiency can be improved relative to the level reached by the most efficient both in terms of input usage and in terms of emissions generated.

4.1 Static approach with undesirable outputs

DEA is a non-parametric frontier approach that estimates efficiency among comparable entities by solving mathematical programming models (Charnes et al., 1978). An alternative to this methodology is the construction of a parametric frontier using econometrics. In our case, the parametric methodology is more appropriate given the limited number of data points. Moreover, DEA is based on the assumption of convexity, which states that for any two points that are feasible, their convex combination is also feasible. This means that for 2 observed Decision Making Units lying on the frontier, one can prove that their convex combination is also feasible. The outcome is a score determined for each firm. We consider n firms with m inputs and s outputs. Let x_{ij} be the inputs and y_{rj} be the outputs of firm j. The mathematical representation of the score is as follows:

$$\theta_j = \frac{\sum_{r=1}^{s} u_r \; y_{rj}}{\sum_{i=1}^{m} v_i \; x_{ij}} \qquad j = 1, 2, 3, ...n \tag{5}$$

where θ_j is the efficiency score of the unit j, u_r and v_i are the weights of output r and input i, y_{rj} and x_{ij} are respectively the quantities of output r and input i observed for unit j [17]. DEA has been widely used in economic literature and a large number of extensions have also emerged such as environmental performance evaluation. Regarding the latter, Scheel (2001) introduced various techniques to address the challenge of incorporating environmental externalities in DEA, while Zhou et al. (2008) presented a literature review of the application of DEA in environmental and energy efficiency studies. Basically, we consider that the production of any "desirable" output is accompanied by the joint production of "undesirable" output such as CO_2. To incorporate undesirable outputs in the DEA model, a Directional Distance Function (DDF) technique is used. As explained by Chung et al. (1997), this approach "solves the problem caused by the joint production of good and bad outputs", which is ignored in traditional DEA models.

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[17] For more detail see also Färe et al. (1994); Cooper et al. (2007)

This joint production implies to consider the nulljointness and the weak disposability conditions to the traditional DEA model assumptions. This means that if a desirable output is produced, some undesirable outputs are also generated. The latter means that a reduction of undesirable outputs would be costly, in the sense that either resource must be diverted or production must be reduced (*i.e.* reducing undesirable outputs is considered an opportunity cost).

Formally, the nulljointness condition is described such that: if $(x, y^d, y^u) \in T$ and $y^u = 0$, then $y^d = 0$. The weak disposability assumption is described such that: if $(x, y^d, y^u) \in T$ and $\theta \in [0;1]$, then $(x, \theta y^d, \theta y^u) \in T$, where we have x, the vector of inputs, y^d the vector of desirable outputs and y^u the vector of undesirable outputs. We also define T as the reference technology that consists of all feasible combinations of inputs x, and outputs y^d and y^u. The DDF with undesirable outputs is defined as follows:

$$\overrightarrow{D}_j(x, y^d, y^u) = max\{\theta : (x, y^d, y^u) + (\theta g_x, \theta g_{y^d}, \theta g_{y^u}) \in T\} \tag{6}$$

where the directional vector $g = (g_x, g_{y^d}, g_{y^u})$ determines the direction in which efficiency is measured, such that $g = (g_{y^d}, g_{y^u}) = (y^d, -y^u)$ measuring the most feasible increase of desirable outputs simultaneously to a proportional decrease of undesirable outputs, with respect to constant quantity of inputs (Chung et al. (1997); Dubrocard and Prombo (2012)). Hence the DDF becomes:

$$\overrightarrow{D}_j(x, y^d, y^u) = max\{\theta : (x, y^d, y^u) + (\theta g_{y^d}, -\theta g_{y^u}) \in T\} \tag{7}$$

The value of the directional efficiency measure $\overrightarrow{D}_j$, represents the distance between observation (y^d, y^u) and a point $(y^d + \theta g_{y^d}, y^u - \theta g_{y^u})$ on the production frontier. It projects the value observed for firm j along the pre-assigned direction corresponding to the output vector $g_y = (y^d, y^u)$. Following the developments of DEA model with undesirable outputs made by Aparicio et al. (2015), Alvarez et al. (2016) defines the following program to compute the efficiency score for each unit j:

$$\begin{aligned}
\overrightarrow{D}_j(x_j, y_j^d, y_j^u) = \quad & \max_{\theta,\lambda} \quad \theta_j \\
& \text{subject to} \\
& X\lambda \leq x_j \\
& Y^d\lambda \geq y_j^d + \theta y_j^d \\
& Y^u\lambda \leq y_j^u - \theta y_j^u \\
& max\{y_i^u\} \geq y_j^u - \theta y_j^u \\
& \lambda \geq 0
\end{aligned} \tag{8}$$

where $j = 1, 2, ..., n$ is the observed firm, $X = (x_1, x_2, ..., x_m)$ and $Y = (y_1, y_2, ..., y_s)$ are the input and output vectors of m and s dimension respectively, $\lambda = (\lambda_1 .... \lambda_n)$ is a semi-positive vector. Hence, considering undesirable outputs, we have $y = (y^d, y^u)$. The optimal solution $0 \leq \theta_i \leq 1$ is computed for each firm. If $\theta_i = 0$, the firm is considered as efficient since there is no difference between the observed values and the efficient production frontier. A value of $\theta_i > 0$ shows inefficiency meaning that the estimated values $(\lambda X, \lambda Y^d, \lambda Y^u)$ outperform the observed values (x_j, y_j^d, y_j^u).

4.2 Dynamic approach: the Malmquist-Luenberger Productivity Index (MLPI)

Based on the DDF approach previously explained, Chung et al. (1997) developed the MLPI. Unlike its static counterpart based on cross-sectional data, the non parametric MLPI uses time-series data and also includes undesirable outputs. This index measures the change in productivity by comparing its relative efficiency in two different time periods. Thus, we are able to dissociate efficiency change and technical change. The former is called ”the catch-up effect.” It refers to the technical efficiency improvement between period 1 and 2(hereafter MLTEC). The latter corresponds to a ”frontier-shift effect” which is the change in the reference frontier from period 1 to period 2 (hereafter MLTC).

We consider $(x_j^t, y_j^{t,d}, y_j^{t,u})$ observed in $t = 1, 2$, while $\theta^{1,1}$ and $\theta^{2,2}$ are the efficiency scores of period one and two computed from program (8). The first superscript is the time period and the second superscript is the reference technology. We also define the intertemporal score $\theta^{2,1}$ assessing the observations of period two $(x_j^2, y_j^{2,d}, y_j^{2,u})$ with respect to technology in period one $(X^1, Y^{1,d}, Y^{2,u})$. The programme becomes:

$$\begin{aligned}
\overrightarrow{D}_j(x_j^2, y_j^{2,d}, y_j^{2,u}) = \quad & \max_{\theta,\lambda} \quad && \theta_j^{2,1} \\
& \text{subject to} && \\
& && X^1\lambda \leq x_j^2 \\
& && Y^{1,d}\lambda \geq y_j^{2,d} + \theta y_j^{2,d} \\
& && Y^{1,u}\lambda \leq y_j^{2,u} - \theta y_j^{2,u} \\
& && max\{y_i^{t,u}\} \geq y_j^{2,u} - \theta y_j^{2,u} \\
& && \lambda \geq 0
\end{aligned} \tag{9}$$

An equivalent program is used to compute $\theta^{1,2}$ so that given a sequence of two periods, we can define the MLPI as [18]:

$$MLPI = \overbrace{(1+\theta^{1,1}/1+\theta^{2,2})}^{MLTEC} \times \underbrace{(1+\theta^{2,2}/1+\theta^{2,1}) \times (1+\theta^{1,2}/1+\theta^{1,1})]^{\frac{1}{2}}}_{MLTC}$$

where the first component is the change in technical efficiency and the second is the technical change. If $MLPI > 1$, the unit is able to produce more desirable output with less input and undesirable output, while $MLPI = 1$ means the productivity remains unchanged, and $MLPI < 1$ captures a productivity decline.

5 Efficiency and environmental performance results

We summarise the results of the DEA methodology in terms of input usage in Figure 6. The twelve firms in our database produce a crude steel output with the following two main materials: coking coal (vertical axis) and iron ore (horizontal axis). The firms also produce an undesirable output which is the volume of CO_2e emissions (not represented in Figure 6). From this data, we can compute the material consumption intensity for each firm and the efficient frontier for the two periods before and after the switch of the

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[18] See Alvarez et al. (2016)

EU ETS allocation methods. The 2007-2012 frontier is represented by a dashed line and the different firm's position as compared to that frontier are represented as dots, while the continuous line represents the 2013-2017 frontier and the different firm's position as compared to that frontier are diamonds.

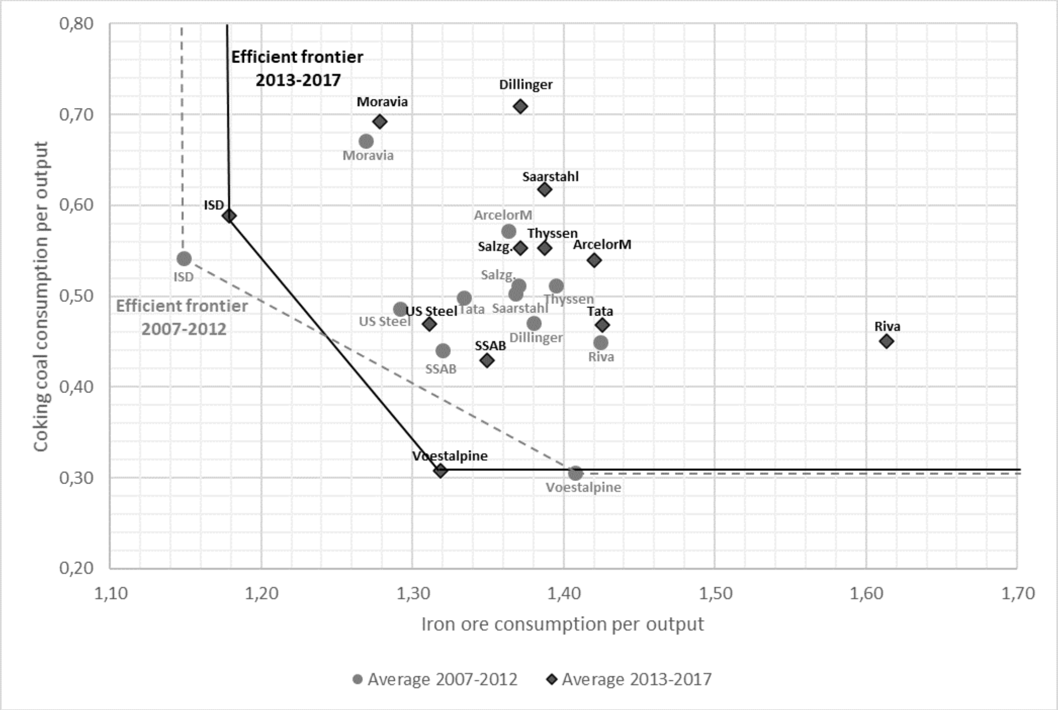

Figure 6: Input intensities and efficient frontiers for the periods 2007-2012 and 2013-2017

We first observe that ISD Dunafer and Voestalpine remain the most efficient firms across the two periods since they are on the frontier. The latter has even been able to decreased its intensity from the first to the second period. We also observe the relative distance to the frontiers of the two main steelmakers: ArcelorMittal and ThyssenKrupp. Both of the firms, who we showed have most profited from OA-profits, are very inefficient and have increased their inefficiency between Phase II and III (*i.e.* the relative input intensity given by the distance to the frontier is longer for Phase III than for Phase II for both firms).

Unlike what we could expect, here the leader is not the most efficient firm in consumption of inputs (or in terms of emissions as we will show). Among other reasons, this can be explained by a vertical integration strategy set up by ArcelorMittal and Tata Steel through which the firm acquired its upstream mining assets [19] avoiding the important soaring prices through the 2000s. For instance, regarding the iron ore which, in 2011, represented approximately 40% of the total cost in steelmaking (Faure, 2012), the price rose from US$ 12 per tonne in 2002 [20] to more than US$ 150 per tonne, ten years later.

Regarding other inputs: labor represented 10% of total costs in 2011 while energy represented 12%. ArcelorMittal entered the European market with an external growth

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[19] In 2007, ArcelorMittal's CEO estimated that 46% of its material consumption was provided by its own deposits, and 65% was set up as a 2012 goal (source: Usine Nouvelle (in French); www.usinenouvelle.com/article/arcelormittal-assoit-son-leadership.N23648).

[20] Yearly average nominal price, 62% of the content (source: International Monetary Fund)

strategy in general. Labor was cheaper in the Central and Eastern European countries like Romania and Poland where ArcelorMittal invested, while energy costs where lower in France, where the firm also bought integrated plants in 2006.

The third dimension in our frontier analysis, CO_2e emissions, could not be represented in Figure 6 but it is worth analysing closely. Using the cross-sectional data and the results of the frontier analysis we compute the relative CO_2e yearly efficiency score (details in Appendix). We then order firms from the most to the less efficient in Table 7.

Table 7: Ranking of firms according to their CO_2e emission efficiency

Firm	Average	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Voestalpine	1	1	1	1	1	1	1	1	1	1	1	1
ISD Dunafer	2	1	1	1	1	1	1	1	3	1	1	1
Moravia Steel	3	1	1	1	6	5	4	4	1	3	2	2
Salzgitter AG	4	4	2	6	5	2	2	3	2	4	7	3
ThyssenKrupp	5	1	1	4	3	3	3	6	7	6	4	4
SSAB	6	2	7	2	1	4	6	7	4	9	3	1
US Steel	7	5	6	5	2	6	5	2	5	7	5	5
Saarstahl	8	3	4	8	8	7	7	5	6	5	6	6
Tata Steel	9	1	3	1	9	10	2	10	1	2	11	9
Dillinger Hütte	10	7	5	3	7	6	9	8	8	11	10	7
Riva	11	6	8	7	4	9	8	11	10	8	8	10
ArcelorMittal	12	8	9	3	10	10	8	9	9	10	9	8

We observe that the two firms on the efficient frontier (Figure 6), Voestalpine and ISD Dunafer, are also the most CO_2-efficient. Regarding the bottom of the ranking, we find that, on average, between 2007 and 2017, the market leader is also the least CO_2-efficient.

In the previous section that studied OA-profits (see Table 6, Figure 4 and Figure 5) we showed the important advantage that the EU-ETS gave to the leader across Phase I and Phase II. Here we observe that ArcelorMittal is the least efficient compared to the other steelmakers, both in terms of emissions and in terms of input usage in general. Conversely, the three most efficient firms, Voestalpine, ISD Dunafer and Moravia Steel, are also the ones who have had the lowest cumulative OA-profits over 2007-2017 as analyzed in the previous section.

Result *Surplus of allowances and the resulting OA-profits are not due to mitigation efforts resulting in CO_2e efficiency. Additionally, market leaders are the least efficient overall.*

Let us now analyze the dynamic CO_2e efficiency through the Malmquist-Luenberger Productivity Index (MLPI) comparing average input and output values for Phase II and Phase III, respectively (see Table 8).

Results of the MLPI in Table 8 indicate that Voestalpine is the firm who has mostly improved its productivity in Phase III as compared to Phse II. This improvement is due to the "frontier-shift effect" reflected in an $MLTC > 1$ which can be interpreted as the capacity to produce more outputs with lower inputs and less emissions (or less undesired output in this case). On the contrary, Riva and SSAB did not improve its efficiency in Phase III as compared to Phase II. These results are in line with results shown in the rankings (Table 7) and appears to be mainly driven by technical efficiency losses due to

Table 8: Productivity change between Phase II and Phase III

Firm	MLPI	MLTEC	MLTC
Voestalpine	1.0736	1.0000	1.0736
Saarstahl	1.0497	1.0385	1.0108
ThyssenKrupp	1.0224	0.9999	1.0225
Salzgitter AG	1.0099	1.0076	1.0022
Tata Steel	1.0072	1.0008	1.0065
US Steel	1.0032	1.0014	1.0018
Dillinger Hütte	1.0026	0.9954	1.0073
Moravia Steel	0.9979	1.0104	0.9875
ArcelorMittal	0.9868	0.9688	1.0186
ISD Dunafer	0.9781	1.0000	0.9781
Riva	0.9384	0.9016	1.0409
SSAB	0.9373	0.9091	1.0310

inability to "catch-up" ($MLTEC < 1$). We also observe that except for few firms, the efficiency improvements have not been mayor since scores are all close to one. Let us now extend the MLPI analyses by including the free allocation of EUAs as an additional input. The heterogeneous "subsidy" in the form of free EUAs, considered here as inputs, indeed makes the ranking different from the one observed in Table 8 (see Table 9).

Table 9: Productivity change considering free EUAs as an input

Firm	MLPI	MLTEC	MLTC
Tata Steel	1.3161	1.0819	1.2165
Saarstahl	1.1932	1.0599	1.1258
Moravia Steel	1.1520	1.0456	1.1017
Voestalpine	1.1352	1.0000	1.1352
Dillinger Hütte	1.1305	1.0330	1.0943
US Steel	1.1223	1.0376	1.0816
Salzgitter AG	1.1046	1.0076	1.0962
ArcelorMittal	1.0518	0.9832	1.0698
ThyssenKrupp	1.0224	0.9999	1.0225
ISD Dunafer	0.9770	1.0000	0.9770
SSAB	0.9747	0.9158	1.0643
Riva	0.9384	0.9016	1.0409

The scores obtained in Table 9 reflect how efficient the firms have been in their use of input (and undesired CO_2e emissions output) considering the number of free EUAs received in each period. The high score for eight of the twelve firms is mostly due to the fact that the allocation of EUAs decreased in Phase III as compared to Phase II. Tata Steel has been the one that mostly improved between Phase II and Phase III. This Table also shows that the efficiency improvements of Voestalpine that we observed in the previous table were not driven by the free allocations. Conversely, the increase in the number of free allowances given to Riva between in Phase III as compared to Phase II, combined with its lower efficiency performance compared to others, push it towards the bottom of the ranking in Table 9.

Result *The EU-ETS has not given enough incentives for firms to increase their* CO_2e *efficiency. This is particularly true for market leaders that are close to the bottom of the ranking in terms of efficiency gains.*

6 Conclusion

The steel industry accounts for the highest share of CO_2e emissions in the manufacturing sector. The switch of methodology used to allocate EUAs between Phase II and Phase III was supposed to tackle over-allocations and reflect the CO_2e intensity of installations. Our results show that over-allocations remained important even after such change. We have also studied alternative allocation rules finding that a benchmark considering the 10% most efficient firms or an Output-Based Allocation would have exerted stronger pressure to invest in a low carbon process.

In Phase IV (2021-2030) the steel industry will continue to receive free allocations based on historical output, but now using the average of 2013-2017 as a reference for the 2021-2025 period, and the average of 2018-2022 for the 2026-2030 period.[21] Regarding the benchmark value BM, the coefficient will be updated yearly by a 0.2% until the end of the Phase.[22] Finally, the cross-sectoral correction factor (CSCF) will now reflect the decreasing cap of -55% of emissions at 2030 established by the European Commission. On top of the changes to free allocation calculations just mentioned, these allocations will be phased-out in accordance with the rhythm of implementation of the Carbon Border Adjustment Mechanism (CBAM) in the steel industry. Phasing-out free allocations is expected in 2032 at the earliest (European Parliament's proposal) or 2035 at the latest (as proposed by the European Commission and the European Council). Since this is an ongoing discussion, the results herein contribute in this regard. Precisely, the findings of this paper suggest that the crude steel industry is not strongly exposed to international competition and would not merit free allocations in the first place. Moreover, the results show that the market is concentrated and that firms with most market power are the ones profiting from the highest over-allocation profits. Finally, after performing a frontier analysis, we find that the market leader is also the least efficient in using iron ore and coking coal (*i.e.* the two main inputs) to produce crude steel and the least efficient in terms of CO_2e intensity.

Our findings suggest the EU-ETS has failed to provide incentives for decarbonization in this sector (and that did not foster an increase in efficiency). Our results are in line with Venmans (2016) that shows for the ceramic industry that over-allocation of permits refrained managers from including carbon gains in payback times. They are also in line with Dechezleprêtre et al. (2018) that shows that the EU-ETS led to an increase in regulated firms' revenues and fixed assets and that the negative competitiveness effect of the EU-ETS has been overplayed.

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[21] Directive (EU) 2018/410 amends Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments.

[22] This is again different from what happens to other sectors that receive free allowances, for which the benchmark value will be decreased yearly by a coefficient ranging from 0.2% to 1.6% and the starting value will be determined according to CO_2e emissions in 2016-2017, and updated for 2026-2030.

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Appendix

Pearson correlation coefficients

In the following Table 10 we show the strong correlation between OA-profits and market power.

Table 10: Pearson correlation coefficient between LI and OA-profits

	Phase I		Phase II and III	
	LI	OA-profits million EUR	LI	OA-profits million EUR
Arcelor Mittal*	1,332	1,024	5,483	4,361
ThyssenKrupp	626	-77.6	2,229	2,839
Tata Steel	528	203.1	2,182	1,356
Ilva	324	55.1	1,034	1,261
Voestalpine	188	45.7	903	170.6
SSAB*	240	228.1	850	813.9
Salzgitter AG	222	2.5	1,002	1,161
US Steel	167	1.8	736	182.9
Dillinger Hütte	86	15.8	401	162.8
Moravia Steel	90	2.5	433	70.1
Saarstahl	100	23.9	419	227
ISD Dunafer	62	56.8	241	55.7
Pearson coef.	0.84		0.94	

**Note: OA-profits from Arcelor and Mittal together in Phase I; OA from Rautarrukki included in SSAB's.*

CO_2 emission efficiency score

From the linear model defined in (8) and based on our cross sectional data, we can compute the relative CO_2 emission efficiency score. Results are given in the following Table 11:

Table 11: Static CO_2 emission performance scores

Firm	Average	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Voestalpine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ISD Dunafer	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000
Moravia Steel	0.041	0.000	0.000	0.000	0.083	0.086	0.103	0.037	0.000	0.072	0.024	0.049
Salzgitter AG	0.045	0.027	0.031	0.059	0.056	0.028	0.044	0.025	0.009	0.088	0.064	0.062
ThyssenKrupp	0.055	0.000	0.000	0.045	0.033	0.040	0.073	0.081	0.085	0.123	0.057	0.064
SSAB	0.068	0.005	0.114	0.037	0.000	0.083	0.129	0.096	0.052	0.187	0.043	0.000
US Steel	0.071	0.042	0.104	0.050	0.020	0.116	0.121	0.002	0.054	0.126	0.062	0.081
Saarstahl	0.096	0.019	0.072	0.153	0.124	0.142	0.143	0.058	0.055	0.096	0.063	0.131
Tata Steel	0.102	0.000	0.057	0.000	0.153	0.274	0.044	0.185	0.000	0.045	0.179	0.179
Dillinger Hütte	0.120	0.089	0.084	0.038	0.112	0.116	0.181	0.135	0.086	0.203	0.144	0.138
Riva	0.134	0.057	0.144	0.087	0.045	0.172	0.159	0.201	0.121	0.173	0.114	0.198
ArcelorMittal	0.154	0.143	0.238	0.038	0.179	0.154	0.206	0.146	0.117	0.199	0.134	0.144