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Effects of European emission unit allowance auctions on corporate profitability

Maria Carratù [a], Bruno Chiarini [a,*], Paolo Piselli [b]

[a] University of Naples Parthenope (Department of Economic and Legal Studies), Italy
[b] Bank of Italy, Economics and Statistics Department, Italy

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ABSTRACT

During Phase 3 of the EU Emission Trading System (ETS), to remedy the so-called *windfall profits* obtained by companies that benefited from the free allocation of emission permits, the EU introduced an auction-based method for the allocation of carbon emission allowances. We estimate the effect on firms' profits from participating in auctions during Phase 3 of the EU ETS using a propensity score matching approach. The work shows that the introduction of the new market mechanism for allocating carbon emission allowances has no significant effect on corporate profits, whatever the measure of profitability used. From a policy standpoint, this result seems to suggest that this new allocation mechanism might fail to improve the incentives for companies to increase their production cost efficiency or to invest in breakthrough technologies that reduce CO_2. The rather flat auction price trend seems to support this conclusion.

1. Introduction[1]

The aim of this paper is to provide an assessment of the impact of the New Auction Regulation for the allocation of emission allowances on the profitability of European firms. This mechanism for the allocation of permits could indirectly provide information on the propensity of these companies to switch to more efficient production in terms of costs or green technologies (Scotchmer, 2011; Denicolò, 1999; Jung et al., 1996). We use a dataset created by a merger of the EUTL and AMADEUS: the first contains plant-level carbon emissions and allowances data, and the second provides firm-level budget items for the period 2009–2016. In this paper, we focus on the EU ETS's third phase, which started in early 2013.

The initiation of the EU ETS was divided into 2 phases: the trial phase (2005–2007) and the second phase (2008–2012), which coincides with the first commitment period of the Kyoto Protocol. The first phase was a pilot phase: no banking or exchanging of permits across phases was allowed, and allowances were allocated for free (grandfathering). The trading rules as well as the initial allocation of pollution permits changed substantially in the second phase: the total number of permits allocated was much lower; the penalty for noncompliance was higher (from 40 euros per ton of CO_2 in the first phase to 100 euros per ton), and banking of permits across phases was introduced. However, in the second phase, grandfathering remained the default allocation method. In this way, CO_2 emitters have largely been compensated for the compliance costs of European legislation, receiving huge amounts of free allowances based on their historical emissions, which generated *windfall profits*,[2] especially for those sectors that were able to pass their compliance costs through to consumer prices (Lise et al., 2010; Joltreau and Sommerfeld, 2019; Sijm et al., 2008).

Therefore, in 2013, at the dawn of the third phase of the EU ETS, policymakers introduced auctions[3] as the default method of allocating European Union emission unit allowances (EUAs) that were no longer based on the historical carbon emissions[4] of polluting sectors. The new

* Corresponding author.
E-mail address: bruno.chiarini@uniparthenope.it (B. Chiarini).

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[2] For instance, between 2008 and 2014, the energy industry earned approximately €24 million from the EU ETS. European industry as a whole made extraordinary profits of approximately 8 billion euros. Most profits were made in Germany, the United Kingdom, Spain, France and Italy.

[3] The EU ETS will allocate the 90% of the allowances via auction and the remaining 10% will be allocated to the less wealthy EU member states for the purposes of solidarity, growth and interconnections.

[4] Auctions ensure that the allocation takes place according to a market benchmark.

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allocation mechanism made it possible to limit long positions on emission permits, highlighting the real imbalances between the allowances received and the stock of carbon emissions.

An emission trading scheme (ETS) is expected to lead to new costs for companies because it requires firms to either buy permits to pollute or, alternatively, to bear the cost of abatement. As a result, many analyses have investigated the issue of the impact of the ETS on firm economic performance and competitiveness. However, existing ex post empirical analyses on the impact of the EU ETS on firm performance have reached mixed conclusions. Although some (few) studies have found positive effects of the EU ETS on the economic performance of companies, other (many) papers have found negative effects or no impact at all (Martin et al., 2016; Convery, 2009; Marin et al. 2018). The limitation of these works is that they are based on the period of grandfathering allocation, when permits were free and allowances were treated as an asset.[5] However, from 2013 on, with the third phase and the introduction of an auction-based allocative mechanism for the allowances, the allowances represent a cost for complying firms. Therefore, the interest in the impact on firm economic performance of the new mechanism is twofold: testing the economic impact of a more costly mechanism and testing its effectiveness as a climate change policy instrument, if higher costs of lower profit for polluting firms could represent an incentive to focus on emission reduction or innovation in clean technology.[6]

To the best of our knowledge, there are few works that study the impact of the introduction of the auction mechanism on profit indicators. Our aim is to fill this gap by investigating the consequences of the New Auction Regulation framework for the profitability of EU ETS firms using quasi-experiments through the application of matching methods.[7] This analysis is important in terms of examining the ability of the new regulation to affect the profits of firms and indirectly induce them to shift their investments toward cleaner technologies.

In contrast to previous works, to take into account the economic impact of the New Auction Regulation, we do not consider participation in the ETS market *per se* as the policy under scrutiny, which would involve conducting empirical exercises comparing ETS-regulated and nonregulated firms. Instead, we estimate the excess emission effect with respect to the allowances as a proxy for the participation of a firm in the auctions. Furthermore, using updated data on recent phases of the EU ETS, we extend the analysis to a more complete group of European countries (EU-26) than those considered in previous studies, which are often focused on a single country.

The paper is organized as follows: In the next section, we present the economic literature on this topic and the models proposed to evaluate the policy. *Section 3* illustrates the data and provides the descriptive analysis; *Section 4* describes the treatment; *Section 5* presents the model used to detect the effects of auctions on some outcome variables; *Section 6* reports the main estimation results; *Section 7* discusses the main policy implications and concludes the paper.

2. Literature review

The transition from grandfathering to auctions entails the evaluation of pollution permits, which is reflected as a cost for companies in polluting sectors, and therefore should lead to a reduction in carbon emissions. Indeed, emission allowances, if considered costs on balance sheets, could contribute to reducing profits and indirectly increase the incentive to reduce pollution (Schleich et al., 2009).

In the economic literature, there are various studies concerning the effect of carbon policies on firm characteristics such as competitiveness, cost, profits, and employment, mostly focusing on specific industrial sectors or single countries.

Anger and Oberndorfer (2008) estimate the impact on firm revenues and employment for a large sample of German firms within Phase 1 of the EU ETS, finding that the allowance allocation did not have a significant impact on the performance and employment of regulated firms.

Petrick and Wagner (2014) estimate the EU ETS's causal impact on German manufacturing companies and find no evidence that emission trading reduced the employment, turnover or exports of affected firms between 2007 and 2010. Lutz (2016) discover that the EU ETS did not significantly affect companies' productivity in the German manufacturing sector during the second compliance period. Similarly, Jaraité and Di Maria (2012) report that emission trading did not represent a driver of the profitability of Lithuanian firms in Phases 1 and 2 of the EU ETS.

Klemetsen et al. (2016) study the impact of the EU ETS on Norwegian companies via *propensity score matching*, considering non-ETS companies as a control sample, and find that value added and productivity are positively affected by carbon policy during the second compliance phase of the EU ETS, possibly due to the availability of free allowances and pass-through of additional marginal costs to consumers.

Yu (2011) use a difference-in-difference approach to estimate the effect of the EU ETS on the profitability of a sample of Swedish energy firms by comparing firms with overallocations and firms with underallocations. His results in general suggest no significant impact in 2005 and a negative significant impact in 2006. The subsample analysis suggests that the profitability of firms with over- and underallocations was affected differently by the EU ETS in 2005 but not in 2006.

Other studies cover a larger selection of European countries.

Chan et al. (2013) implement a difference-in-differences (DID) method to study the effects of ETS regulation on the three most polluting industries covered under the program: power, cement, and iron and steel. They compare participant and non-participant firms and find that the overall effects on the cement and iron and steel sectors are trivial, but there is a positive effect on the material costs and revenues for the power sector during 2005–2009. Abrell et al. (2011), studying more than 2000 European firms from 2005 to 2008, find that the free allocation and ex post verified emission are correlated and that the EU ETS did not significantly affect profits, employment or value added during the first phase or the beginning of the second phase. Finally, Marin et al. (2018), by comparing the economic performance of participants and similar non-EU ETS firms during Phases I and II, find that treated firms seem to display performance gains from the EU ETS, with positive effects on turnover, markup, investment intensity and labor productivity.

In our view, the main explanation for the result of this vast literature, which finds basically no evidence of negative effects of the emission regulation on firm competitiveness and profitability, is related to the period under scrutiny, a period of free allocation of allowances, extensive overallocation and EUA prices that stayed at low levels (Joltreau and Sommerfeld, 2019; Klemetsen et al., 2016; Sijm et al., 2008).

Reconnecting to the empirical literature that uses quasi-experimental designs, our aim is to study whether European ETS-regulated companies have experienced changes in financial performance in terms of profitability from 2013 onwards, after the introduction of the New Auction Regulation.

3. Data and descriptive evidence

Following Abrell et al. (2011) and Chan et al. (2013), we merge the

[5] The transition from grandfathering to auctions raises issues related to EUA accounting. The "International Financial Reporting Interpretations Committee – IFRIC 3 Emission Rights" states that allowances are intangible assets and must be accounted for at their fair value (Lovell et al., 2010; Wambsganss and Sanford, 1996).

[6] For the EU ETS to be dynamically efficient, it must provide incentives for firms not only to reduce their emissions in the short run but also to invest in innovation of clean technologies (Martin et al., 2016).

[7] As Martin et al. (2016) observe, impact analysis of the EU ETS is still very much a work in progress; this also reflects the nature of the EU ETS as an ongoing and continuously evolving policy instrument. This work strives to keep abreast of empirical research on these regulatory changes.

EUTL and AMADEUS data to obtain a firm-level dataset with a sample of 3307 EU-26[8] companies; upon reshaping it into a panel, we finally have a dataset consisting of 26456 observations covering the period from 2009 to 2016. The European Union Transaction Log (EUTL) contains data on the verified CO_2 emissions and allocated allowances for each installation (i.e., plant) across 48 sectors in the EU countries (EU-28)[9]; the AMADEUS archive contains information on the balance sheet items of European firmsTable A.1.

The sample is divided geographically according to the country of origin of the company and its classification into Northern, Central, Southern, and Eastern Europe[10]. Table A.2 (in the Appendix) reports the distribution percentages based on geographical location; most firms come from Central and Southern Europe, with shares of 39.92% and 29.88%, respectively; the firms from Eastern and Northern Europe represent smaller shares, 17.78% and 12.43%, respectively. Based on the dimension criteria, we classify four types of firms: very large, large, medium-sized, and small. Table A.3 displays the frequency distribution of companies with respect to their size; 41.04% of the sample are very large, 38.35% are large, and the remaining 20.62% are small and medium-sized companies. The industrial sectors are identified using 4-digit aggregate NACE Rev. 2 codes[11]. -Table A.4 shows that our set of firms belong mostly to the manufacturing sector (97.73%), electricity (0.79%), wholesale and retail trade (0.36%), and mining and quarrying (0.27%); the other sectors have a residual distribution percentage. Units are also distinguished with respect to the carbon leakage list[12] Table A.5; as we can see, 65.56% of the firms belong to a carbon leakage sector and hence cannot be subject to the auction regulation[13].

As we can see in Fig. 1, most of the ETS sectors show an imbalance between emission allowances and CO_2 emissions. The graph shows the average CO_2 emissions (gray bar) and EUAs (black bar) allocated to each sector at the aggregate level during Phase 2 and Phase 3 of the EU ETS. Between 2009 and 2012 (left-hand side), most of the sectors show an overallocation of allowances. In particular, sectors such as real estate, mining and quarrying, retail trade, public administration, manufacturing, electricity gas and steam, transport, water supply and waste management, and financial and insurance activities show, on average, a quantity of allocated EUAs that exceeds the amount required to cover polluting emissions. This overallocation could be attributable to the free allowance allocation (i.e., *grandfathering*)[14] in force during Phase 2. Surprisingly, among the sectors that show a lack of permits, we find construction, agriculture, and services. This situation changed during the period 2013–2016 (right-hand side). Sectors that previously had a surplus of EUAs exhibit an imbalance with respect to the amount of emissions produced; this is especially evident for mining and quarrying, manufacturing, and electricity.

In conclusion, during the third Phase, the real needs of companies, in terms of emission coverage, do not correspond to the amount of owned allowances when they are not freely allocated.

Table 1 shows descriptive statistics for firms during Phase 2 (2009–2012) and Phase 3 (2013–2016). The average CO_2 emission level does not statistically differ from the first to the second phase, so we deduce that there is no evidence of a reduction in emissions

During Phase 3. The number of allowances is also higher in the first period (10.32) than in the second period (9.79) and statistically different (the standard deviations are 1.75 and 1.70, respectively). Balance sheet variables, turnover, sales, total assets, and working capital per employee are higher between 2013 and 2016, while costs are lower, but again these differences are not statistically significant.

4. The imbalance between EUAs and CO_2

As we have seen above, during the early stages of the EU ETS (2005–2012), the free allocation of allowances did not encourage firms to reduce their carbon emissions. In fact, the literature has shown that widespread availability of carbon permits affects the proper functioning of the carbon market (Martin et al. 2016; Joltreau and Sommerfeld, 2019). Moreover, in many sectors (for instance, the electricity sector), firms generated huge profits by transferring the potential cost of compliance to the price paid by consumers (Sijm et al., 2008).

All this leads to a natural question: Has the new mechanism of Phase 3 overcome these drawbacks in the carbon market, introducing the correct incentives for firms via the market mechanism?

To answer this question, we must focus on the behavior of companies that have to decide whether to go on the market to buy the missing allowances to comply or, conversely, whether to incur fees/costs in case they fail to or decide not to comply. Accordingly, in our assessment of the new mechanism, we only consider companies with a negative imbalance between their effective emissions and endowment of allowances.

Hence, we calculate the percentage difference between the total allowances and the total emissions in the 2013–2016 period for all firms in polluting sectors (excluding carbon leakage). Any negative imbalance is considered a proxy for the potential cost sustained by firms in purchasing allowances on the market to comply with the scheme.

This imbalance represents a proxy for the policy to which our firms are subject, and in our policy evaluation exercise, it constitutes our treatment variable. We want to test how treated firms' profits are affected by the policy compared to a sample of similar firms that do not display such an imbalance.

The idea of looking at the imbalances between emissions and allowances as a treatment variable is not new. Anger and Oberndorfer (2008) first introduced the idea of the allocation factor, defined as the ratio of the (free) endowment of allocated emissions to the verified emission.[15] An allocation factor larger than 1 suggests that an installation has received allowances that exceed its emission level, whereas the opposite suggests that this installation should either buy additional

[8] Cyprus and Malta are not included because of a lack of data on emissions and EUAs for the period under consideration.

[9] Note that the aviation sector is not included in the dataset because of a lack of data concerning CO_2 emissions in the EUTL for Phase 2 of the EU ETS.

[10] The sample is divided geographically according to the country of origin of the company and its regional classification as follows: Northern Europe (Denmark, Norway, Finland, and Sweden), Central Europe (Austria, Belgium, Czech Republic, France, Germany, Ireland, Luxembourg, Netherlands, and the UK), Eastern Europe (Estonia, Latvia, Liechtenstein, Lithuania, Poland, Bulgaria, Hungary, Romania, Slovenia, and Slovakia), and South Europe (Greece, Italy, Spain, and Portugal).

[11] The NACE Rev. 2 reflects the technological developments and structural changes in the economy between 2000 and 2007; for details, see Eurostat.

[12] The carbon leakage list was first applied to the ETS in 2013 and 2014. Prior to its application, the list had been amended three times: in 2011, 2012 and 2013.

[13] Under the EU ETS, industrial installations deemed to be exposed to a significant risk of carbon leakage receive special treatment to support their competitiveness. Carbon leakage refers to a situation that may occur if, for reasons of costs related to climate policies, businesses transfer production to other countries with laxer emission constraints. This could lead to an increase in total emissions between the two countries. The risk of carbon leakage may be higher in certain energy-intensive industries.To safeguard the competitiveness of industries covered by the EU ETS, producers from sectors and subsectors deemed to be exposed to a significant risk of carbon leakage receive a higher share of free allowances in Phase 3 (2013–2020) than the share of other industrial installations. The sectors and subsectors deemed to be exposed to a risk of carbon leakage are defined in an official list.See https://ec.europa.eu/clima/policies/ets/allowances/leakage_en (on 2020 11 03).

[14] Until the end of the second compliance period (2012), the allocation of allowances involved the drafting of national allocation plans (NAPs) based on historical carbon emissions.

[15] Precisely, the allocation factor measures the allocation of EU emission allowances relative to the actual emissions of the respective entity.

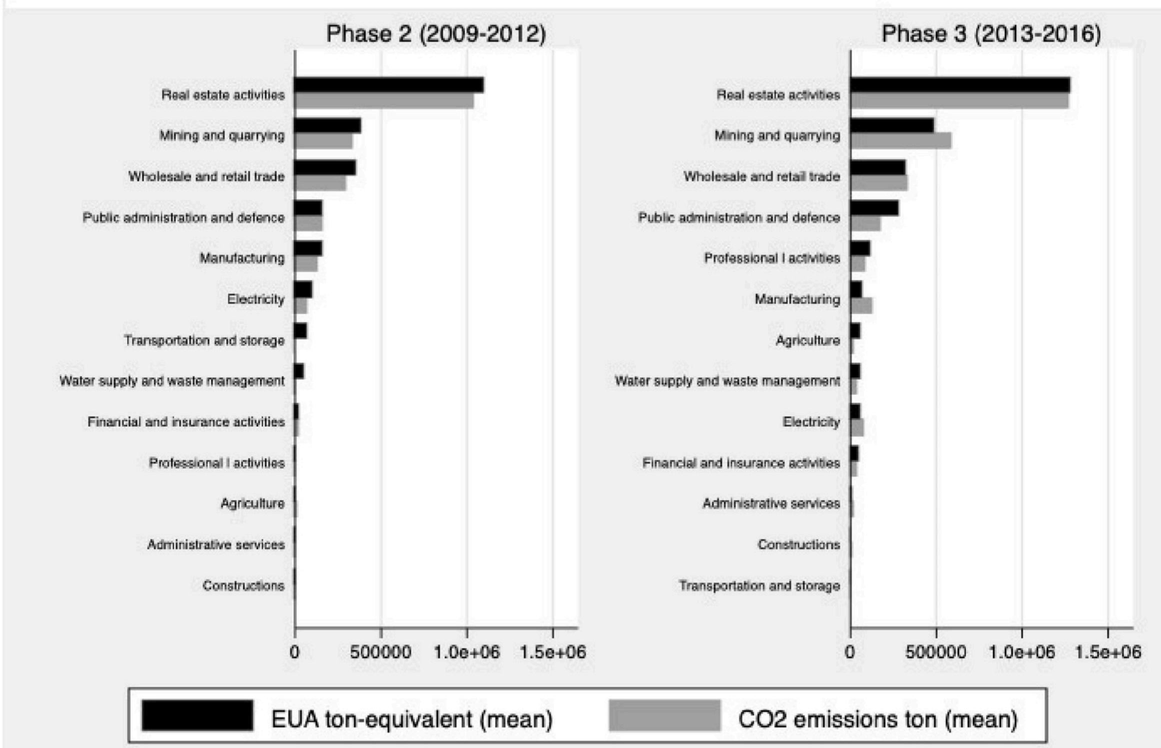

Fig. 1. CO_2 emissions and EUAs (averages) by NACE Rev. 2 sectors (EU ETS Phases 2 and 3). Source: Own elaboration using EUTL data.

Table 1
Descriptive statistics over time: Phase 2 (2009–2012) and Phase 3 (2013–2016).

Phase 2	variable	N	mean	sd	p25	p50	p75
	CO_2 (log)	11064	9.75	2.11	8.66	9.70	10.88
	EUA (log)	10870	10.32	1.75	9.33	10.14	11.21
	turnover (log)	9690	10.64	2.12	9.17	10.69	12.13
	liquidity (log)	5869	0.78	1.81	−0.62	−0.05	2.36
	workcapital (log)	8341	8.80	2.06	7.33	8.85	10.30
	sales (log)	8928	10.50	2.13	9.03	10.55	12.00
	total_asset (log)	10059	10.87	1.93	9.41	10.81	12.28
	lcost (log)	1418	11.13	2.85	9.37	11.39	13.09
	workcap_employ(log)	539	3.84	1.33	3.00	3.91	4.69
Phase 3	**variable**	**N**	**mean**	**sd**	**p25**	**p50**	**p75**
	CO_2 (log)	11043	9.69	2.24	8.68	9.78	10.89
	EUA (log)	10191	9.79	1.70	8.84	9.72	10.71
	turnover (log)	9618	10.67	2.18	9.21	10.78	12.19
	liquidity (log)	7843	0.79	1.82	−0.62	−0.04	2.36
	workcapital (log)	8222	8.74	2.13	7.30	8.86	10.26
	sales (log)	8823	10.53	2.19	9.07	10.65	12.06
	total_asset (log)	9989	10.90	1.95	9.44	10.86	12.32
	lcost (log)	1691	10.92	2.96	9.19	11.24	12.96
	workcap_employ(log)	2007	3.87	1.26	3.09	3.95	4.74

N is the number of observations; sd is the standard deviation; and p25, p50, p75 are percentiles.

emission allowances or abate some of its emissions to comply with the EU ETS[16].

Potentially, any imbalance would require firms to participate in auctions. However, we exclude small imbalances (negative but close to zero) that may have negligible economic effects and undermine our results, and we choose a threshold based on the distribution of the imbalances. Thus, we consider treated firms to be those with imbalances below the median (approximately −12%; see Table 2)[17]. We expect firms with a higher imbalance to suffer more from the effects of the treatment because they may have to pay more to abate their polluting emissions.

Fig. 2 shows the percentage imbalance between allowances and CO_2

[16] The allocation factor is also used in Abrell et al. (2011) to compare the performance of firms with overallocations and underallocations.

[17] The threshold was also chosen to maintain a sensible sample size; the median allows us to have a sufficient number of companies in the treated group. Other thresholds have been tested without any significant impact on the results.

Table 2
Summary statistics of the treatment - variable.

Imbalance			
Percentiles			
1%	−1		
5%	−1		
10%	−1	Observations	23,680
25%	−0.431		
50%	−0.125	Mean	53.62
		Std. Dev.	1850
75%	0.266		
90%	1.576		
95%	5.668		
99%	89.99		

emissions during Phase 2 (pretreatment) and Phase 3 (treatment) of the EU ETS. For a better representation of the data, we truncate the graph to only include values of the size of imbalance between −100 and 100. The former is the maximum deficit in percentage terms when the initial allowances are null; the latter indicates a 100% deficit. In the treatment period (right-hand side), the percentage of observations with an imbalance included in the negative range [0;-100] is higher than that observed in the pre-treatment (left-hand side).

It is worth noting that imbalances are on average more frequent in Phase 3 as a result of a more rigorous allowance allocation system, which pushes firms to turn to the market.

The correlation matrix (Table 3) shows that for treated firms, the imbalance is strongly negatively correlated with the EUA value during the treatment period; firms that have more EUAs are less likely to be treated.

Fig. 3 shows the trend in EUA prices between 2008 and 2019. The EUA primary market spot price (dotted line) reached 30.52 euros in 2008, fell during the crisis period (2008–2009), and followed a constant trend until 2012, when it went up to 8.3 euros. After the creation of the primary auction market for EUAs in -2012-, EUA auction prices (solid line) followed a constant trend until the end of 2016.[18] Since 2017, there has been an increase in spot prices, reaching 23 euros in 2019, while auction prices remain low at approximately 7 euros.

Table 4 shows the firms' classification according to the treatment. They are split into 13228 observations before 2013 and after 2013; the treated companies number 3416 (1708 each period), and the non-treated companies number 23040 (11520 each period).

We also calculate the value of the allowances as the auction price per quantity of EUA for each company and the weight that this variable has on other balance sheet items, e.g., costs, sales, and total assets.

Table 5shows descriptive statistics on balance sheet items distinguished by treated and untreated firms. The treated firms display an average value of allowances (i.e., eua_value) of 12.11, which is higher than the average of 11.89 of the nontreated sample. The weight of the allowance on costs is greater for treated (4.97%) than for untreated firms (2.98%); conversely, the weight of the allowances for the remaining ratios is higher for untreated than treated firms. We also consider the 2018 average EUA spot prices to check for any changes in the balance sheet variables (see- Table A.6 in the appendix). The value of allowances increases for both samples. The ratios on the balance sheet variables increases for untreated firms, with the exception of the cost ratio, which decreases from 2.98% to 2.68%. For the treated sample, the weight of eua_value on assets, financial revenues and sales decreases, but the cost ratio increases from 4.97% to 7.13%.

[18] Starting from 2012 up until 2019, the spot prices (dashed line) and auction prices (solid line) overlap; this justifies our use of spot prices as proxy for auctions before 2012.

5. Methods

The foundation of the policy evaluation exercise is the possibility of comparing a sample of firms (in our case) under the policy (the treated ones) to a sample of other firms as similar as possible to the former but not subject to the policy under scrutiny. The average difference in the outcome variable (profits in our case) between the two samples is the effect of the policy we want to measure. This effect is called the average treatment effects on treated (ATT). In equation form,

$$\tau = E\{Y_{1i} - Y_{0i} | treat_i = 1\} \tag{1}$$

where Y_{1i} is the sample of firms i affected by the treatment/policy and Y_{0i} is the sample of firms similar but not subject to the treatment (the so-called counterfactual group).

The challenge of this econometric approach is to select this subsample of similar firms and to find a proper method to measure this similarity.

The counterfactual sample is a theoretical construct because if a firm is treated it cannot be untreated at the same time, but if we know its characteristics, we can find/select its ideal counterfactual companion firm. This approach is called *selection on observables.* Among several methods to carry out this selection, we implement *propensity score matching* (Rosenbaum and Rubin, 1985).

In this approach, treated and untreated firms are matched based on their probability of receiving the treatment. In our case, the propensity score is defined as the conditional probability of participating in an allowance auction (i.e., the treatment) given pretreatment characteristics:

$$p(X) = Pr(treat = 1|X) = E(treat|X) \tag{2}$$

where $treat = \{0, 1\}$ is a binary variable that takes the value 1 for treated companies and 0 otherwise; X is the multidimensional vector of pre-treatment characteristics. In our analysis, this vector includes balance sheet variables such as working capital per employee, fixed assets, turnover, level of CO_2 emission, and NACE dummies for the manufacturing and electricity sectors. After identifying the variables that affect the probability of treatment, the second step consists of testing that the average propensity score of treated and control units does not differ.

To compute the counterfactual sample, we use three different matching measures, *nearest-neighbor matching, kernel matching, and stratification matching* (Rubin, 1990; Becker and Ichino, 2002; Caliendo and Kopeinig, 2008; Stuart and Rubin, 2004; Stuart, 2010). Below, we briefly give an intuitive characterization.

The nearest-neighbor matching sets

$$\mathrm{C}_i \;=\; \min_j \;||\; \mathrm{p}_i \;-\; \mathrm{p}_j \;|| \tag{3}$$

where C_i is the set of control units matched to the treated unit i with an estimated value of the propensity score of pi. The ATT estimation (eq. (1)) is calculated by:

$$\frac{1}{N^T}\sum_{i\in T} Y_i^T - \sum_{j\in C} w_j y_j^c \tag{4}$$

where the number of units in the treated group is denoted by NT; y_j^c is the counterfactual sample, which respects condition (2); and the weights w_j are the probability of being included in the treated group, defined by $wj \;=\; \Sigma iwij$.

The average treatment effect using the kernel matching estimator is given by

$$\frac{1}{N^T}\sum_{i\in T}\left\{ Y_i^T - \frac{\sum_{j\in C} Y_j^C G\left(\frac{p_i - p_j}{h_n}\right)}{\sum_{k\in C} G\left(\frac{p_k - p_i}{h_n}\right)} \right\} \tag{5}$$

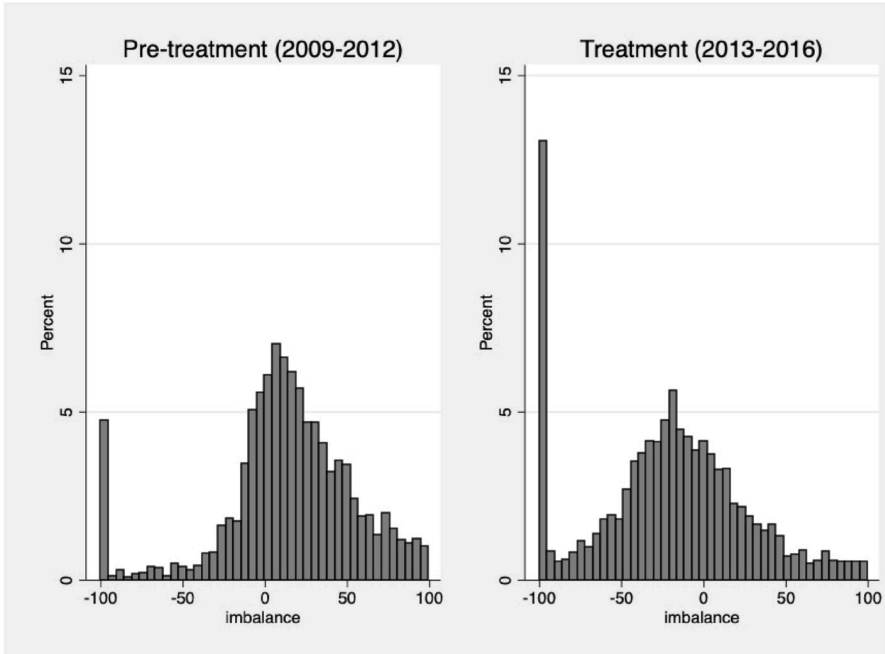

Fig. 2. Percentage of firms (y-axis) and their imbalance (%) between allowances and CO_2 emissions before (2009–2012) and during treatment (2013–2016).

Table 3
Correlation between allowance value and imbalance for treated firms in Phase 3.

	eua_asset	imbalance
eua_asset	1.00	
Imbalance	−0.279	1.00

Notes: *eua_asset* is given by the eua_value over total assets; *eua_value* is given by the auction price times the annual number of allowances.

where *G(·)* is a kernel function with bandwidth parameter h_n, which defines the weights of units close to Y_i^T.

The estimator of the ATT based on the stratification method is then computed using the following formula:

$$T^s = \sum_{q=1}^{Q} T_q^s \frac{\sum_{i \in I(q)} D_i}{\sum_{\nabla i} D_i} \tag{6}$$

where the weight for each block is given by the corresponding fraction of treated units and Q is the number of blocks.

6. Estimation results

Following Petrick and Wagner (2014) and Klemetsen et al. (2016), using firm-level data, we estimate the average treatment effect on treated using propensity score matching to test the effect of the introduction of the EU ETS allowance auction policy on profitability indicators. As our measures of profitability (outcome variable), we consider the main profitability indexes: ROA, ROE, ROCE, EBIT margin, EBITDA margin and Profit margin.

The estimates of propensity scores (Table 6) are obtained by *probit* regression on 1716 treated firms and 310 controls. They show that the probability of being treated is positively linked to CO_2 emission but negatively linked with the NACE sector. Furthermore, country, working capital, turnover and fixed assets do not significantly affect the

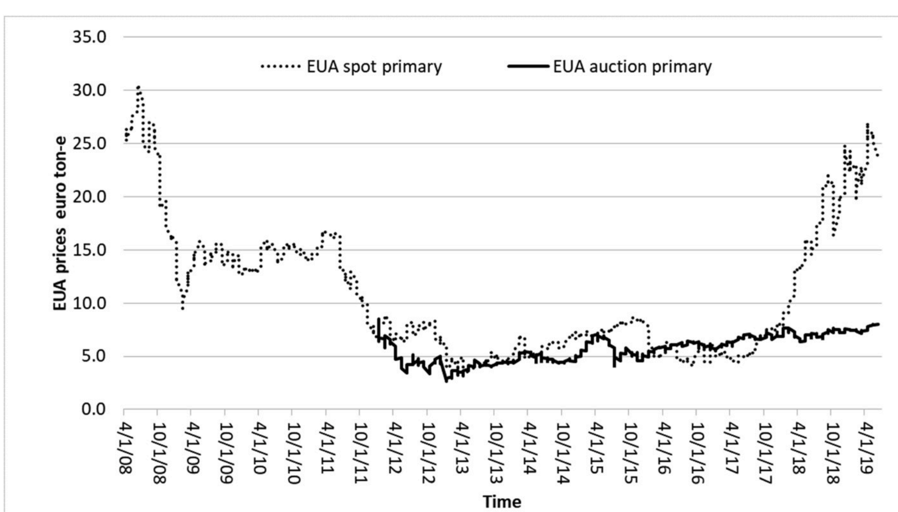

Fig. 3. EUA spot and auction historical prices (EU ETS Phases 2 and 3).

Table 4
Frequency table of companies by treatment and period.

Treat	Time		Total
	Before 2013	After 2013	
0	11520	11520	23040
1	1708	1708	3416
Total	13228	13228	26456

Treat is a dummy: 1 if treated; 0 otherwise.
Time is a dummy: 0 if pre-treatment period (year $<$ 2013); 1 if treatment period (year$\geq$2013).

Table 7 shows the distribution of observations when the balancing property and common support conditions are satisfied. The first condition (balancing property) implies that the distribution of relevant pretreatment variables is the same for the treatment and control groups. The second one (common support) means that propensity scores between the treated and control groups are compared only if the pretreatment values of variables (the regressors in the propensity score estimations) lie in the same range (the so-called common support region). In fact, when the treatment and control groups do not share the same common support, their outcomes could differ because of some differences in pretreatment characteristics and not as a result of treatment (e.g., a strong difference in assets).

Table 5
Impact of allowances on firms' balance sheets during EU ETS Phases 2 and 3.

Untreated firms	Variable	N	mean	sd	p25	p50	p75
	eua_value(log)	18253	11.89	1.83	10.85	11.76	12.88
	pceua_sales	15447	0.0057	0.0362	0.0000	0.0004	0.0022
	pceua_cost	14293	0.0298	0.2063	0.0000	0.0001	0.0014
	pceua_finrev	15747	0.0065	0.0386	0.0000	0.0001	0.0012
	pceua_finexp	2735	0.0057	0.0487	0.0000	0.0001	0.0006
	pceua_asset	17396	0.0051	0.0254	0.0000	0.0005	0.0027
Treated firms	**Variable**	**N**	**mean**	**sd**	**p25**	**p50**	**p75**
	eua_value(log)	2808	12.11	1.62	11.08	11.95	13.03
	pceua_sales	2304	0.0049	0.0282	0.0001	0.0004	0.0016
	pceua_cost	2191	0.0497	0.4076	0.0000	0.0001	0.0007
	pceua_finrev	2375	0.0035	0.0166	0.0000	0.0001	0.0013
	pceua_finexp	374	0.0046	0.0314	0.0000	0.0001	0.0005
	pceua_asset	2652	0.0043	0.0177	0.0001	0.0008	0.0026

Eua_value (unit) is given by the auction price times the annual number of allowances. pceua_cost is the percentage ratio between eua_value and costs; pceua_finrev is the percentage ratio between eua_value and financial revenue; pceua_finexp is the percentage ratio between eua_value and financial expenses; pceua_asset is the percentage ratio between eua_value and total assets. *N* is the number of observations; *sd* is the standard deviation; p25, p50, and p75 are percentiles.

Table 6
Estimation of the propensity score using probit regression.

Probit regression					*N* =	2304
					LR chi2(7) =	64.36
					Pvalue =	0.000
Log likelihood = 836.063					Pseudo R2 =	0.0371
Explanatory vars.	**Coeff.**	**Std. Err.**	**z**	**P > z**	**[95% Conf.Interval]**	
country_code	0.000	0.004	0.000	0.999	−0.006	0.009
workcap_empoyee	0.022	0.029	0.760	0.449	−0.001	0.000
Fix asset	−0.0423	0.027	−1.560	0.118	−0.119	−0.015
Turnover	0.023	0.034	0.670	0.503	0.000	0.125
CO_2	0.087	0.019	4.700	0.000***	0.065	0.135
NACE1 (manufacturing)	−1.000	0.255	−5510	0.000***	−1.821	−0.863
NACE2 (electricity)	−0.991	0.453	−2.410	0.016**	−1.687	−0.008
_cons	−0.416	0.374	−1110	0.265	−1.372	0.017

Note: The common support option has been selected. The region of common support is [0.0319, 0.7751].
*p < 0.1, **p < 0.05, ***p < 0.01.

probability of treatment. The fact that none of the dimensional variables (working capital, turnover and fixed assets) are significant is probably the result of our sample of firms, largely made up of medium-size to large firms. We also note that the geographical location may have no influence on the treatment because, although the auctions are in force in all ETS countries, there are still 8 countries that partially continue to benefit from free allowances.[19] In contrast, emissions represents an important driver that expresses the need for companies to participate in auctions or to obtain costly allowances; in fact, an increase in emission leads to greater demand for allowances.

To check that the treated firms and control firms, in the absence of treatment[20], are comparable and do not have significant differences in the output variables (the so-called ceteris paribus conditions), we perform a *two-sample t-test* of differences in means of the outcome variables. We also compute the same means for the whole sample of untreated firms (before matching) to underline the performance improvement of matching. The results of the tests are shown in Table 8. In the absence of matching (left column), the means of ROA for the treated and control groups are significantly different; this means that the two samples are not completely comparable because there are observable characteristics that make them different. In contrast, the t-tests on

[19] The least wealthy EU member states (Bulgaria, Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Poland, and Romania) were granted free allowances as an additional source of revenue to help them invest in reducing the carbon intensity of their economies and adapt to climate change.

[20] We consider the period 2009–2012, when the regulation on auctions was not yet in force.

Table 7
Distribution of observations when balancing property and common support conditions are satisfied.

Propensity scores	Controls	Treated	Total
0.032	195	6	201
0.100	333	31	364
0.125	488	117	605
0.150	539	109	648
0.200	152	29	181
0.400	0	1	1
0.600	9	17	26
Total	1716	310	2026

Note: The common support option has been selected. This table shows the lower bound, the number of treated firms and the number of controls for each block. The balancing property is satisfied. The final number of blocks is 7; this number of blocks ensures that the mean propensity score is not different for treated and control firms in each block.

ROE, ROCE, EBIT margin, profit margin and EBITDA do not show significant differences in means in the pretreatment period. Comparing these results with those obtained after matching (right column), we note that the homogeneity among the treated and control companies is greater. Before the treatment, the outcome variables exhibit similar average values in terms of profit indicators (including ROA). This exercise is important because a potential difference in the means of the outcome variables between the two samples could invalidate the results of the treatment effects.

The estimates of the average treatment effects (ATT) on the output variables are presented in Table 9. We use three different matching methods: *model 1* applies the nearest-neighbor method (eq. (4)) for calculating the ATT, *model 2* applies kernel matching (eq. (5)), and *model 3* applies the stratification method (eq. (6)).

The results for ROA are robust in each model, showing positive but nonsignificant ATT coefficients (p-values 0.480, 1.012, 0.988 in model 1, model 2, and model 3, respectively); the ROE outcome also shows positive but nonsignificant statistics (1.801, 2.311, and 2.195 for the three models, respectively). Additionally, the profit margin and the EBIT margin have positive and nonsignificant effects from the treatment, while EBITDA shows negative but still nonsignificant ATT coefficients. These results show that for firms that have an imbalance between emissions and allowances during Phase 3 of the ETS, the purchase of allowances does not affect profits, irrespective of the profit measure used.

7. Conclusion and policy implications

The literature has shown that during the early stages of the EU ETS (2005–2012), the free allocation of allowances did not encourage firms to reduce their carbon emissions. In the short term, the widespread availability of carbon permits affects the proper functioning of the carbon market. In the long term, overallocation could affect the ETS's ability to achieve more cost-effective emission reduction targets. Furthermore, it must be emphasized that the system was not able to adapt the supply of allowances to demand; for example, during the last downturn, the decline in economic activity was accompanied by a reduction in emissions, but the allowances remained adequate to cover historical emission levels, with consequent influences on prices, which remained quite flat.

In this paper, we provide an estimation of the effects of the introduction of emission allowance auctions on the profitability indicators of ETS firms during the period 2013–2016 (Phase 3 of the EU ETS).

The allowances represent a potential cost that may affect the ability of firms to generate profits. In the literature, there are numerous studies on the effect of policies on business outcomes; many works have addressed the subject from a qualitative point of view, considering the effect that the creation of ETS markets has produced on companies. We link to the branch of the empirical literature that studies the effects of ETS treatment using propensity score matching, applied to a dataset that contains firm-level data on CO_2 emissions, emission unit allowances (EUAs) and balance sheet items. We perform the exercise in two phases. First, we perform a probit regression to evaluate the probability of being

Table 9
Estimation of average treatment effects (ATT) on profitability indicators using different matching methods.

	(1)	(2)	(3)
	ATTnd	ATTk	ATTs
ROA	0.480	1.012	0.988
	(1.209)	*(1.141)*	*(0.825)*
ROE	1.801	2.311	2.195
	(2.941)	*(2.190)*	*(2.141)*
ROCE	0.184	0.357	0.386
	(3.941)	*(2.006)*	*(2.201)*
PROFIT	16.949	12.152	11.376
	(16.364)	*(10.953)*	*(9.745)*
EBITDA	−0.305	−0.235	−0.183
	(1.320)	*(1.063)*	*(1.172)*
EBIT	0.089	1.127	1.498
	(2.874)	*(2.289)*	*(1.971)*

Notes: Bootstrapping of standard errors in parentheses; ATTnd is the coefficient for average treatment effects on treated using nearest-neighbor matching; ATTk is the coefficient using kernel propensity score matching; ATTs is the effect estimated based on stratification-; standard errors are in brackets; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 8
Ceteris paribus conditions between treated and untreated firms (before matching) and treated and control groups (matched firms).

		Untreated firms (no matching)				Control group (matched firms)			
Outcome variable	Treat	N	mean	Std. Err.	t-stat	N	mean	Std. Err.	t-stat
ROA	0	11591	1.562	0.117	−1.966	224	4.325	0.072	0.037
	1	1748	2.187	0.269		29	4.325	1.85	
ROE	0	9815	3.486	0.378	−0.239	115	10.812	2.522	1.028
	1	1512	3.733	0.954		14	3.0571	6.120	
ROCE	0	1556	5.996	0.4301	0.754	138	7.035	1.318	0.118
	1	210	5.048	1.243		15	6.546	3.305	
EBIT	0	8076	10.280	0.284	−0.775	164	12.617	1.88	0.802
	1	1208	10.887	0.709		25	8.668	2.545	
PROFIT	0	10221	26.737	1.649	−0.546	187	40.819	13.763	0.182
	1	1508	29.202	3.642		31	34.570	15.364	
EBITDA	0	4993	13.018	0.263	1.361	133	14.999	1.287	0.903
	1	728	12.038	0.546		19	11.811	2.436	

Notes: Two-sample *t*-test with equal variances on means of outcome variables with and without propensity score matching. Null hypothesis Ho: diff = 0; alternative hypothesis Ha: diff ! = 0. Treat equals 0 for untreated/control group and 1 for treated firms. N is the number of observations in each group. The test is run in the pretreatment period (2009–2012).

treated (i.e., participating in EUA auctions) as a function of a series of variables. Second, we apply different matching methods to estimate the average treatment effects of the allowance auction policy. CO_2 emissions represent an important driver of the need to buy allowances on markets; indeed, the greater the emissions, the greater the number of allowances to be returned at the end of the compliance period.

Our results show that there are no significant effects of participation in allowance auctions on profit indicators. This result supports what has previously been stated by other studies (Anger and Oberndorfer, 2008; Yu, 2011; Abrell et al., 2011) with the crucial distinction that the latter concern the first two phases of the EU ETS. The negative effects on the EBITDA margin follow the theoretical evidence provided by Demailly and Quirion (2008), although there is no statistically significant evidence. We can conclude that allowance auctions do not have a significant impact on EU ETS firm profitability and do not represent a driver of profits in Phase 3. Contrary to previous phases, this result seems to rule out the possibility that windfall profits are currently being obtained. This would suggest that the enhanced achievement of emission reduction targets, linked to the introduction of auctions, did not occur, although we do not directly measure the impact of auctions on CO_2. Indeed, it seems that auctions contributed to reducing the overallocation of allowances.

The fact that an auction system could fail to curb emissions is not a completely unexpected result. Here, we prove that profitability is likely not to be affected enough to work as an enforcement mechanism. Although a detailed analysis is not the purpose of this work, it worth mentioning some of the explanations for this ineffectiveness that have been put forward by the literature.

1. EUA prices, illustrated in Fig. 3, reflect market fundamentals that did not tend towards a reduction in supply. In particular, the fact that prices stayed at low levels during most of the third phase actually made the imposition of an auction price fictitious. In this way, it is still more convenient for companies to receive permits through auctions rather than to implement the use of clean technologies or to reduce emissions. Although during the third phase EUA allocation is linked to a benchmark instead of historical emissions, we still observe that for some sectors, the overallocation of allowances remains evident (e.g., agriculture, water supply, real estate); the oversupply of allowances has continued to keep prices low during the second and third phases of the ETS. Indeed, as Fig. 3 shows, auction prices and spot prices recorded the same trend during the period 2013–2016; thus, it was cheaper for firms to buy allowances on the secondary market than on the primary market. Thus, there is no incentive to reduce pollution (see, within the vast literature on EUA pricing, Lutz et al., 2013; Koch et al., 2014).
2. The presence of speculators and derivatives markets may have an impact. Here, we consider only those firms that were potential participants in auctions; however, there are also other market participants (e.g., investment banks) that can act as speculators, whose influence could contribute to increases in the prices of allowances (see, among others, Lucia et al., 2015; Cretì and Joëts, 2017; Berta et al., 2017; Castellucci and D'Amato, 2009). The possibility of purchasing allowances on futures markets makes hedging activity more feasible for firms, and therefore, it reduces the demand for allowances on spot markets.
3. The auction is binding on the basis of the productive sector; unfortunately, due to the risk of carbon relocation and loss of competitiveness, the majority of the ETS sectors were considered to exhibit "carbon leakage", and therefore continued to receive free allowances (see, for instance, Clò, 2010; Martin et al., 2014).
4. The impact of the allowances on the balance sheet items is important; for example, firms that exhibited an imbalance of EUA also exhibited a larger impact of the EUA value on costs; however, it is possible for some firms in some sectors (e.g., electricity) to transfer the cost of compliance to the price paid by consumers, which could still represent a limit on the effectiveness of auctions.

We believe that the effects of the reform will be more evident when the allowances are distributed entirely through auctions and all ETS sectors are involved (e.g., the aviation sector). We also note that since 2018, with the increase in the market prices of allowances, these permits now have a greater impact on budget items, particularly on costs, which could incentivize emission reductions. Furthermore, allowance auctions could become more effective with the introduction of the Market Stability Reserve (MSR)[21], a mechanism that provides for the creation of a reserve through the withdrawal of excess allowances from the market. This mechanism could improve the ETS's resilience to major shocks by adjusting the supply of allowances to be auctioned (Joltreau and Sommerfeld, 2019; Sijm et al., 2008).

Given the continuous amendments to the regulation, the study of the phenomenon of EUA auctions on firm performance will have to be updated and deepened, extending the time span or deploying new methodologies to identify the causal link. Our hope is to be able to extend the analysis in this direction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Maria Carratù: Data curation, Software, Methodology, Writing - original draft. **Bruno Chiarini:** Conceptualization, Supervision. **Paolo Piselli:** Visualization, Formal analysis, Conceptualization, Methodology, Writing - review & editing.

APPENDIX

Table A.1
List of variables

Variable name	Variable label	Source
Year	From 2009 to 2016	–
Geo	Macro-regions classification	–
country_code	ISO 3166-1 geographical codes	EUTL, Euroepan Environmental Agency (EEA)
NACE1	Dummy for sector: 1 if manufacturing; 0 otherwise	AMADEUS, Bureau van Dijk

(*continued on next page*)

[21] Decision (EU) 2015/1814 of the European Parliament and of the Council of 6 October 2015, amending Directive 2003/87/EC.

Table A.1 (*continued*)

Variable name	Variable label	Source
NACE2	Dummy for sector: 1 if electricity generators; 0 otherwise	AMADEUS, Bureau van Dijk
CO2	CO2 emissions in logarithm (ton CO_2-equivalent)	EUTL, Euroepan Environmental Agency (EEA)
EUA	Emission Unit Allowances in logarithm (1-euro ton equivalent)	EUTL, Euroepan Environmental Agency (EEA)
Imbalance	Phase 3 EUA minus CO_2 EMISSIONS (%)	–
n_employees	Number of employees	AMADEUS, Bureau van Dijk
ROA	Return on Asset after taxes	AMADEUS, Bureau van Dijk
ROE	Return on Equity after taxes	AMADEUS, Bureau van Dijk
ROCE	Return on Capital Employed	AMADEUS, Bureau van Dijk
EBITDA	Earning Before Interests and Taxes, Depreciation and Amortization (margin %)	AMADEUS, Bureau van Dijk
EBIT	Earning Before Interests and Taxes - EBIT over sales (margin %)	AMADEUS, Bureau van Dijk
ROCE	Return on Capital Employed before taxes	AMADEUS, Bureau van Dijk
PROFIT	Net income divided by revenue (margin%)	AMADEUS, Bureau van Dijk
Fix Asset	Fixed Asset	AMADEUS, Bureau van Dijk
Turnover	Turnover in logarithm (k euro)	AMADEUS, Bureau van Dijk
eua_value	Auction value as auction price per EUA quantity in logarithm (thousands)	–
pceua_asset	Auction value over total assets (%)	–
pceua_finrev	Auction value over financial revenues (%)	–
pceua_costs	Auction value over costs (%)	–
pceua_sales	Auction value over sales (%)	–
pceua_finexp	Auction value over financial expenses (k euro)	–
workcap_empoyee	Working capital per employee (logartihm)	AMADEUS, Bureau van Dijk
Treat	dummy: 1 if treated; 0 if not-treated	–
Time	dummy 0 if pre-treatment; 1 treatment period	–

Table A.2
Firms by region

Macro-region classification	N	%	Cum.
Centre Europe	10560	39.92	39.92
South Europe	7904	29.88	69.79
East Europe	4704	17.78	87.57
North Europe	3288	12.43	100.00
Total	26456	100.00	

The European region is classified into 4 areas (North, Centre, East, and South), depending on the geographical location of the company in accordance with country ISOcode.[22]

Table A.3
Firm size

Size	N	%	Cum.
Very large company	10857	41.04	41.04
Large company	5454	38.35	79.38
Small and Medium-sized companies	10145	20.62	100
Total	26456	100.00	

The size is referred to a proxy of firm's dimension as reported in AMADEUS; N is the absolute frequency.

Table A.4
Firm by sectors (NACE rev.2 classification).

NACE Rev. 2 main section	N	%	Cum.
Manufacturing	25856	97.73	97.73
Electricity, gas, steam, and air conditioning	208	0.79	98.52
Wholesale and retail trade, repair of vehicles	96	0.36	98.88
Mining and quarrying	72	0.27	99.15
Financial and insurance activities	48	0.18	99.33
Professional/scientific/technical activities	32	0.12	99.46
Water supply, sewerage, waste management	32	0.12	99.58
Administrative and support service activities	24	0.09	99.67
Public administration and defence	24	0.09	99.76
Agriculture, forestry, and fishing	16	0.06	99.82
Constructions	16	0.06	99.88
Real estate activities	16	0.06	99.94
Transportation and storage	16	0.06	100.00
Total	26456	100.00	

The industrial sectors are identified NACE rev.2 stand for the using 4-digits aggregate high-level sector code. N is the absolute frequency.

[22] The Country_ISO code is the internationally recognized two-digits alfa-numeric codification; it is like an acronym, that stands for a country or a state.

Table A.5
Carbon leakage firms

Carbon_leakage sectors	N	%	Cum.
0	9112	34.44	34.44
1	17344	65.56	100.00
Total	26456	100.00	

*Carbon*_leakage is dummy: 1 if the firm belongs to the carbon leakage list; 0 otherwise.

Table A.6
Impact of allowances on firm's balance sheets during Phase 2 and Phase 3 - EU ETS at 2018 annual average price.

Non-Treated firms	variable	N	mean	sd	p25	p50	p75
	eua_value	18000	12.74	1.78	11.78	12.61	13.68
	pceua_asset	17000	0.0052	0.0559	0.0000	0.0004	0.0021
	pceua_costs	2700	0.0268	0.1678	0.0000	0.0001	0.0013
	pceua_finrev	14000	0.0066	0.0799	0.0000	0.0001	0.0009
	pceua_finexp	16000	0.0056	0.0618	0.0000	0.0001	0.0006
	pceua_sales	15000	0.0059	0.0743	0.0000	0.0003	0.0017
Treated firms	variable	N	mean	sd	p25	p50	p75
	eua_value	2800	12.97	1.56	12.02	12.81	13.81
	pceua_asset	2700	0.0035	0.0153	0.0001	0.0006	0.0020
	pceua_costs	3740	0.0713	0.6186	0.0000	0.0002	0.0007
	pceua_finrev	2200	0.0025	0.0097	0.0000	0.0001	0.0009
	pceua_finexp	2400	0.0051	0.0484	0.0000	0.0001	0.0005
	pceua_sales	2300	0.0039	0.0204	0.0001	0.0003	0.0012

Notes: *eua_value* - is given by the average auction price in 2018 times the annual amount of allowances. *pceua_cost* is the percentage ratio between eua_value and costs; *pceua_finrev* is the percentage ratio between eua_value and financial revenue; *pceua_finexp* is the percentage ratio between eua_value and financial expenses; *pceua_asset* is the percentage ratio between eua_value and total assets. *N* is the number of observations; sd is the standard deviation; and p25, p50, and p75 are percentiles.

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