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Abstract

Focusing on the industrial sector of the EU ETS, this study identifies and analyses the entries and the exits of installations into and from the system over the period 2005-2013. The overall number of exits was notable relative to the number of installations, and significantly greater than that of the entries. Further, we estimate a hazard model for the risk of an installation exiting the EU ETS, which identifies a number of different factors referring to the installation, the firm, and the economy, explaining the occurrence of this event. In addition to these, an "end-of-phase effect" is found, whereby the chances of exit were significantly higher in the final years of the EU ETS Phases I and II. This effect, related to the rules concerning the closure of an installation and the withdrawal of the relative allowances, is detrimental to the allocative efficiency of the system and, therefore, to its cost-effectiveness in emissions abatement. The evidence provided by the study and some of its methodological aspects may be useful for future attempts to identify investment leakage in the EU ETS.

Keywords

EU ETS, entries and exits, manufacturing sector, hazard model, end-of-phase effect.

1. Introduction

The EU Emissions Trading System (EU ETS) constrains the greenhouse gas emissions of the EU's electricity sector and energy-intensive industries. The EU ETS is currently the most prominent cap-and-trade scheme in the world and the cornerstone of EU climate policy. Launched in 2005, its first decade has been turbulent in certain respects, principally due to the effects of the economic crisis. A large excess supply of emission allowances meant that the allowance price (hereafter also referred to as carbon price) plummeted and will probably stay lower than originally expected for a few years to come. A low carbon price is problematic in that it fails to trigger investment in emissions abatement, calling into question the relevance of the instrument. Regulatory initiatives for sustaining the allowance price have been taken[1] and the revision of the EU ETS Directive recently proposed by the European Commission posits measures that will also influence the price. Many representatives of the regulated industries have expressed their concerns about the prospective impact of the EU ETS on the competitiveness of the respective sectors. Both the issuance of fewer allowances, as a result of the overall cap tightening, and the progressive substitution of grandfathering by auctioning, as a method for allocating the allowances, mean that the opportunity cost of holding the allowances will (to varying degrees across the sectors) gradually turn into the real cost of purchasing them. Avoiding competitiveness deterioration and ensuing carbon leakage, i.e. emissions moving to regions with less stringent carbon regulation, appears to be the main challenge for the EU ETS today.

A number of studies have provided empirical assessments of carbon leakage in the EU ETS. Martin *et al.* (2014), Dechezleprêtre *et al.* (2014), Petrick and Wagner (2014), Branger *et al.* (2013), Chan *et al.* (2013), Sartor (2012) constitute the bulk of this growing literature. The emerging evidence is quite comforting, as non-negligible emissions reductions are attributed to the EU ETS and no evidence of carbon leakage has been found so far. All of these studies analyze competitiveness effects of unilateral carbon pricing over the short- or medium term. In the long run, competitiveness deterioration due to carbon costs may lead to long-term carbon leakage or what is commonly referred to as investment leakage; that is, relocation of carbon-regulated activities overseas, with permanent losses of jobs and capital use locally. While some studies have framed the problem theoretically (e.g., Cook [2011], Reinaud [2008], Matthes [2008]), to date no empirical contributions exist assessing investment leakage in the EU ETS. As time passes and new data are available, investigating such long-term effects becomes increasingly important and should also become increasingly viable.

This paper offers new evidence concerning the past development of the EU ETS and its functioning. The analysis is relevant to investment leakage, but is not concerned with its identification. We deal with the "symptoms" of investment leakage, but our data do not allow us to ascertain whether investment leakage has been taking place. Using the registry of the EU ETS as primary information source, the paper identifies and analyzes the patterns of installation entries and exits into and from the system[2]. Since the risk of carbon leakage mainly concerns the industrial sector of the EU ETS (rather than the power sector), we focus on the subset of installations operated by manufacturing firms. All such installations located in the 31 countries participating in the EU ETS are considered. As regards the time dimension of the analysis, the span 2005-2013 covers the EU ETS Phases I and II (2005-2007 and 2008-12) as well as the first year of the third trading phase (2013-2020). Installation entries and exits into and from the EU ETS are events of interest in that they imply long-term variations in

[1] The "Back-loading" (Commission Regulation (EU) 176/2014) was a short-term measure for Phase III that postpones the auctioning of 900 million allowances from 2014-2016 to 2019-2020. The second intervention, more important, was the introduction of the Market Stability Reserve (Decision (EU) 2015/1814). This involves a mechanism whereby each year a given amount of allowances for auctioning is moved to a reserve if the allowance surplus passes a maximum threshold and, viceversa, it is returned to the market if the surplus falls below a minimum threshold. This mechanism will be in operation as of 2019.

[2] In the EU ETS, installations are plants or plant subunits.

production activity. Entries signal increased production: they either reflect the operation of a new installation or the expansion of an existing one above the minimum threshold to be subject to the EU ETS. Exits signal reduced production: they either reflect the shutdown of an installation or the reduction of one to a level below the minimum threshold.

Installation entries and exits are dependent on a multitude of variables, including microeconomic, macroeconomic and institutional characteristics or conditions. In the second half of the paper, we explore the significance and the relative importance of a range of such factors within a hazard model for the event of an installation exiting the system. The model allows for both time-invariant and time-varying factors which statistically make an installation more likely to exit the EU ETS. No attempt is made to model installation entries because we are not able to mechanically identify what we call "regulatory entries", that is, installations entering the EU ETS as a result of occasional changes in regulation. The hazard model for installation exits is fitted to a three-tier panel dataset constructed expressly for this study by matching installation-level data with both firm-level- and economy-level data drawn from external sources.

The paper is organized as follows. Section 2 analyses the patterns of the installation entries and exits. Section 3 presents the data and the model used. Section 4 discusses the estimation results. Section 5 concludes.

2. Installation entries and exits

2.1 Identifying entries and exits

The Union registry is the accounting system that keeps track of the ownership of the emission allowances issued under the EU ETS and held in electronic accounts. The EU Transaction Log[3] (EUTL) operates the Union registry by checking, recording and authorizing the transactions of the emission allowances and by verifying the compliance of the installation operators with respect to their emissions and the allowances surrendered. The EUTL interface presents itself as similar to a database comprising two main sections, one devoted to the allowance transactions and the other to the installation operators' compliance status. All EUTL information used in this study is drawn from the compliance section, in which both the installations and the installation operators are identified and the annual amounts of emissions, free allowances received and allowances surrendered are reported[4].

The closure of an Operator Holding Account (OHA), as the accounts tied to an installation are called, marks the end of the corresponding installation's participation in the EU ETS. This event implies either the cessation of the installation's production activity or its production capacity falling below the relevant minimum threshold[5]. For each installation, the EUTL shows the date on which the permit to participate in the EU ETS was issued (the permit entry date) as well as whether and when the same permit expired or was revoked (the permit expiry/revocation date), in which case the account was also closed. However, the latter date does not coincide with the time of cessation or downscale of production activity, which may have taken place even several months earlier. Moreover, the permit entry date may not signal the start or upscale of production activity, defining what we call in this paper an "economic entry". The date may instead reflect a change in regulation whereby a pre-existing plant comes to fall under the EU ETS, constituting a "regulatory entry". As long as we are interested in the

3 http://ec.europa.eu/environment/ets/.

4 Mastering the EUTL for analysis purposes can take some time. Jong (2015) provides a technical description of the EUTL which can help in this endeavor.

5 The thresholds are expressed in terms of production capacity or output. For most sectors, the EU ETS covers installations with a net heat excess of 20 MW. The list of the sector-specific thresholds is found in Annex I to the EU ETS Directive (2003/87/EC, 2009/29/EC).

causes of installation entries and exits, we want to locate such events at the actual time of the leap or drop in production (for entries and exits, respectively). Concerning exits, we can locate the year an installation's production activity ceased or was sufficiently downscaled to drop out of the EU ETS by looking at the installation's emissions. The same general approach is used for identifying the timing of installation entries, though it still leaves us unable to mechanically distinguish between regulatory entries (occurring during the course of a trading phase) and economic entries, these two being defined as above.

Every year, in mid-May, each installation's verified emissions (VE) pertaining to the previous calendar year, *t*, are published in the EUTL. Thus, for a given installation, $VE_t > 0$ implies production activity was carried out during *t*; $VE_t = 0$ implies the installation was idle for the entire year; and missing VE information (if not merely due to administrative delays) means participation in the EU ETS had either terminated or not started yet. Our approach for locating installation entries and exits in correspondence with the leap or drop in production activity rests on this set of simple deductions. Accordingly, we identify the exit year as the last one with positive emissions, conditional on the account having been closed[6]. Since an account can only be closed once, conditioning the exit event on the account being closed rules out the possibility of counting temporary cessations of production activity[7]. In more formal terms,

$$\text{installation } i \text{ is considered to have exited in } t \text{ if } \begin{cases} i\text{'s account is closed} \\ \text{AND} \\ VE_{i,t} > 0 \\ \text{AND} \\ VE_{i,t+n} = 0 \text{ OR} = .\ (\text{missing}),\ \forall n=1,2,\ldots,T\text{-}t \end{cases}$$

where *T* (>*t*) is the most recent year for which VE information is available.

By the same token,

$$\text{installation } i \text{ is considered to have entered in } t \text{ if } \begin{cases} t > 1 \\ \text{AND} \\ VE_{i,t} > 0 \\ \text{AND} \\ VE_{i,t-n} = 0 \text{ OR} = .\ (\text{missing}),\ \forall n=1,2,\ldots,t\text{-}1 \end{cases}$$

where $t = 1$ is the first year the country in which *i* is located participated in the EU ETS.

The entry rule above does not allow for entries occurring in the first year a country joined the EU ETS, that is, in $t = 1$. Without VE information for previous years, it is assumed that the installations with $VE_{t=1} > 0$ had existed since at least the year before. For this reason and because regulatory entries are not distinguished from economic entries, the entry patterns thus derived are not perfectly comparable with the corresponding exit patterns. A second remark is that the exit rule and the entry rule above are not mutually exclusive. That is, they can be both verified for a given installation. This is true for the installations that entered some year after $t = 1$ and exited sometime before *T*[8].

Table 1 shows two distributions of EU ETS installations by the entry and exit events as just defined. The distribution in the left panel includes all the installations with $VE > 0$ in at least one year

6 The EUTL reports the current status of all OHAs as "open" or "closed".

7 It also rules out the possibility of counting installations that opted-out of the EU ETS at the start of Phase III.

8 In theory, an installation could enter and exit in the same year. In practice, such cases are few in number.

between 2005 and 2012. It thus includes all the installations participating in the EU ETS since before 2013, without distinctions as to the type of installation or other characteristics: thermal power plants, manufacturing installations and all other installations are included. The distribution in the right panel only differs in that it is limited to the installations operated by manufacturing firms[9]. It turns out that 59.9% of the installations in this subset have been in the EU ETS since $t = 1$ and never exited, 13.4% entered in $t > 1$, 23.2% exited before $T = 2014$ and 3.6% both entered in $t > 1$ and exited before 2014. The corresponding shares for the distribution of all EU ETS installations (left panel) are similar, only exhibiting slightly fewer exits (21%) and slightly more entries (14.9%).

Table 1 – Installations with positive VE between 2005 and 2012, by entry and exit events

	All installations		Installations operated by manufacturing firms	
Event	number	%	number	%
No entry or exit event	7651	60.3	3891	59.9
Entry	1892	14.9	870	13.4
Exit	2662	21.0	1507	23.2
Entry and exit	481	3.8	232	3.6
Total	12686	100	6500	100

2.2 Distribution of installations

Before focusing on the derived patterns of installation exits and entries, let us inspect the distribution of installations across countries and economic sectors. As the distribution can be rendered at different aggregation levels, the one reported in Table 2 is a working compromise between detail and conciseness. Just as in Table 1 (left panel), all the installations that have been or were (and no longer are) in the EU ETS since before the start of Phase III are considered. Six Member States are by far the most important in terms of number of installations (and emissions), namely Germany (1985), Italy (1216), Spain (1146), UK (1128), France (1118) and Poland (910). The sum of the installations located in these countries – the big six – makes up almost 60% of the total number of installations.

[9] Installations can be classified according to the activity of the operator using NACE information (see Section 2.2 below).

Table 2 – Installations with positive VE between 2005 and 2012, by country and economic sector

	Country							
NACE-based sector	Germany	France	UK	Italy	Spain	Poland	Others	Total
Food	115	143	117	154	109	115	330	1083
Textiles	10	17	5	38	6	3	61	140
Wood	22	6	3	5	19	23	75	153
Paper	183	117	59	180	107	35	300	981
Coke and petroleum prod.	49	14	14	20	15	23	63	198
Chemicals	124	108	84	88	105	17	288	814
Glass	104	52	25	58	39	18	115	411
Bricks	148	56	63	24	284	49	428	1052
Ceramics	58	1	9	5	37	33	82	225
Cement	113	51	38	95	72	50	244	663
Metals	64	33	20	47	33	33	192	422
Other manufacturing	51	43	49	43	17	17	138	358
Non-manufacturing	916	446	592	419	256	489	2644	5762
NA	28	31	50	40	47	5	223	424
Total	1985	1118	1128	1216	1146	910	5183	12686

Note: Table A1, in the Appendix, shows the correspondence between the NACE Rev2 classification and the NACE-based sectors.

Information from outside the EUTL was needed to derive the distribution of the installations by economic sector. This is because the EUTL only reports the sectoral classification defined by the EU ETS Directive (2003/87/EC, 2009/29/EC), which refers to the production activity carried out at the installation level. However, the type of economic activity of the installation operators is clearly important information for economic analyses of the EU ETS. On two occasions, in 2008 and 2014, the European Commission disclosed it by publishing the four-digit NACE codes of the installation operators[10]. The more recent information was thus added to our dataset[11]. Table A1, in the Appendix, shows the correspondence between the NACE-based sectors in Table 2 and the actual NACE (Rev2) classification.

Still with reference to Table 2, the *Non-manufacturing* sector comprises the largest number of installations (5762). All installations operated by non-manufacturing firms, primarily energy companies operating power plants, fall into this sector. As regards the installations operated by manufacturing firms (6500), the *Food* sector is the largest in terms of number of installations. This might be surprising, since the food industry as such is not covered by the EU ETS. The vast majority of the installations operated by food firms, however, are energy production units and therefore fall in the EU ETS *Combustion* sector. The same is true for those operated by firms in the *Textiles* and *Wood* sectors. Table A2, in the Appendix, shows the distribution of the installations operated by manufacturing firms both across the installation-level EU ETS sectors and the firm-level NACE-based sectors. Ultimately, sufficiently detailed NACE information can make the scope of the EU ETS better appreciated and also enhance its economic analysis.

2.3 Entry and exit patterns

The patterns of installation entries and exits, these being identified in the way described, provide a novel piece of evidence concerning the past development of the EU ETS. The graph in Figure 1 pictures the number of exits (negative values) and entries (positive values) of the installations operated by manufacturing firms, across time and countries. Figure 2 only differs from Figure 1 in that the breakdown of entries and exits is by sector instead of country.

[10] In Europe, NACE is the classification of economic activities used in official sectoral statistics.

[11] http://ec.europa.eu/clima/policies/ets/cap/leakage/studies_en.htm.

Fig. 1 – Entries and exits of installations operated by manufacturing firms, by year and country

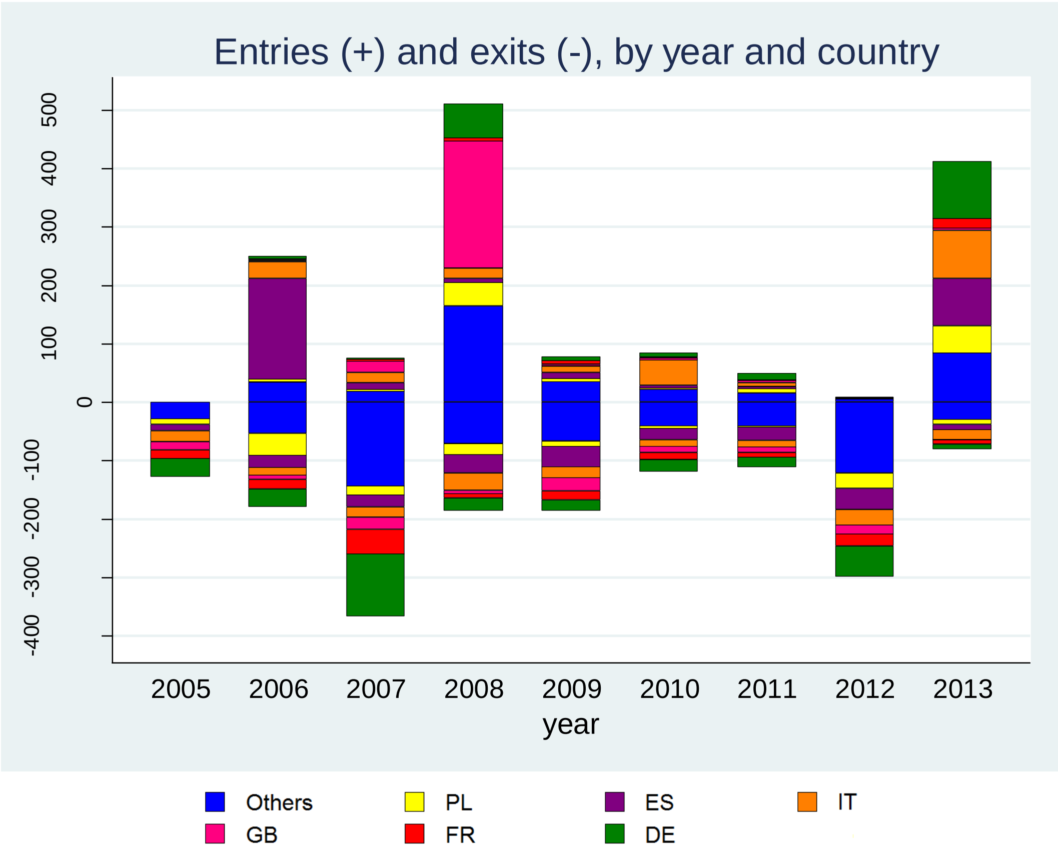
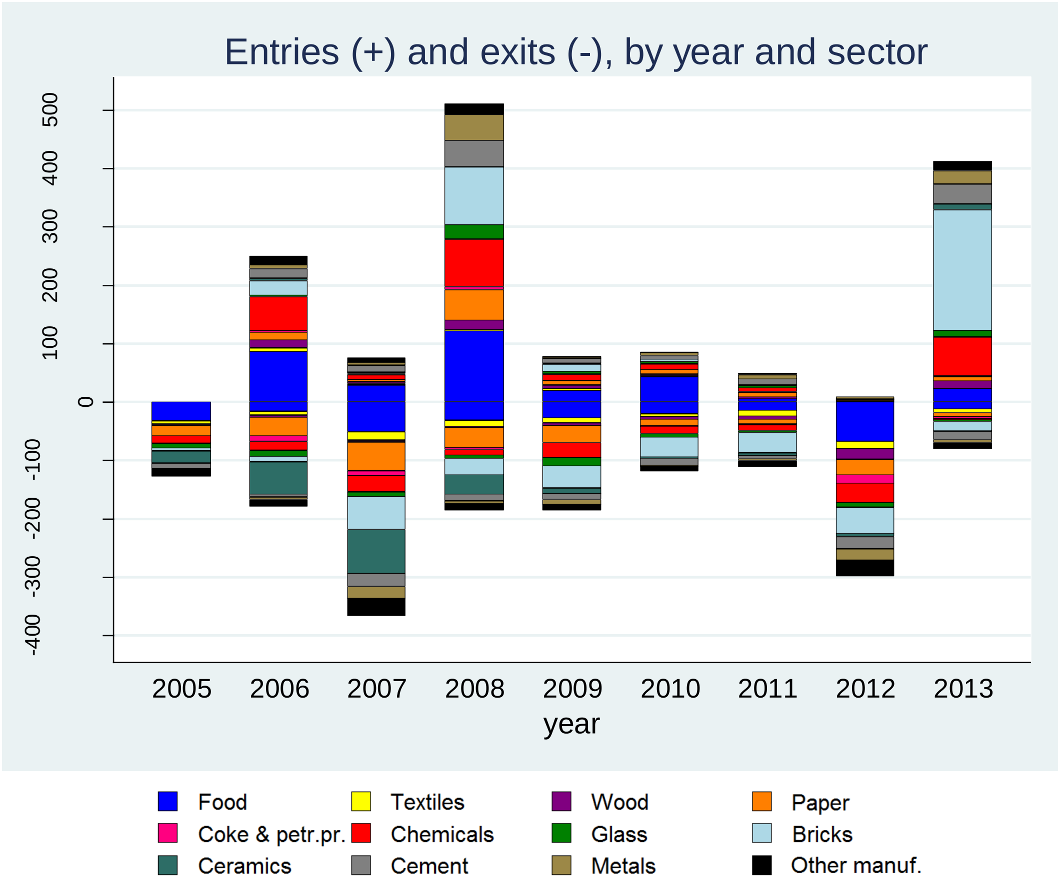


Fig. 2 – Entries and exits of installations operated by manufacturing firms, by year and sector



The pattern of total entries is characterised by three spikes: in 2006, 2008, and 2013. The 2008 spike and the 2013 one coincide with the first years of Phase II and Phase III, respectively. Incidentally, the large number of installation entries observed in 2013 is unrelated to the sector enlargement that came with Phase III, as the new sectors are purposely not considered here. It would thus appear that the first year of a trading phase tends to come with more entries than the others. While this conjecture seems plausible, further investigation would be needed to ascertain whether it is actually true. As to the entries observed in 2008, they partly reflect regulatory changes extending the scope of the EU ETS within the UK. Similarly, the 2006 entries are largely explained by regulatory changes taking place in a single country, which is Spain in this case. In the UK, the increase in the number of regulated installations was mainly the result of the supersedence of the UK ETS (pre-existing to the EU ETS) and the Climate Change Agreements, whereby many installations had been able to opt out of the EU ETS during Phase I (DECC [2009]). In Spain, the regulatory change in question came through an amendment to the first National Allocation Plan[12], which had adopted too restrictive an interpretation of the EU ETS Directive concerning its area of application. These examples demonstrate that very lengthy scrutiny of all the relevant national regulations would be necessary to distinguish between regulatory and economic entries. For this reason, our econometric analysis below only deals with installation exits. Another implication is that the difference in number between exits and entries is from an economic standpoint more significant than it looks: the more entries are in fact regulatory entries, the greater the imbalance between exits and economic entries reflecting increased economic activity.

[12] Government decree Asignación de derechos de emisión a las instalaciones afectadas por la ampliación del ámbito de la ley 1/2005, Acuerdo de consejo de ministros de 14 de Julio de 2006.

The exit patterns elicit a few more considerations. First, the number of exits is remarkable relative to the number of installations. With reference to Table 1 above, 26.8% of the installations operated by manufacturing firms and in the EU ETS since before 2013 exited before 2014. Second, despite regulatory entries being included in the count, significantly more exits than entries are observed overall. As Table 3 shows, net exits (exits minus entries) were 463 over the period 2005-2012, and 202 (= 463 - 261) by the following year (2013). Such a steep reduction in total net exits reflects the inflow of installations with the start of Phase III. Third, net exits are not evenly distributed across sectors (or countries). Over 2005-2013, the two sectors exhibiting the largest installation outflows are the *Ceramics* and *Paper* sectors. In the *Bricks* sector, exits by far outnumbered entries over 2005-2012, but the outflow reversed into an inflow by the end of 2013. Fourth, clearly more exits occurred in 2007 and in 2012 than in other years. This was unexpected, as the economic crisis had not yet started by 2007 nor did it peak in 2012 or shortly before then. However, 2007 and 2012 are the final years of Phase I and Phase II, suggesting that the timing of these exits may be related to the design of the EU ETS. We address this question in the following section.

Table 3 – Net exits of installations operated by manufacturing firms, by country (big six) and sector

	Food	*Textiles*	*Wood*	*Paper*	*Coke & petr. prod.*	*Chemicals*	*Glass*	*Bricks*	*Ceramics*	*Cement*	*Metals*	*Other manufacturing*	Total
2005-2012													
DE	25	0	2	30	20	0	5	45	51	14	-1	10	201
FR	32	0	0	24	0	20	4	3	0	0	0	0	83
GB	-45	0	0	-35	0	-8	-15	-37	0	-16	0	3	-153
IT	-31	7	0	25	0	0	4	0	0	6	-3	-3	5
ES	-58	-3	-4	29	-1	-34	0	47	36	-4	5	-10	3
PL	11	0	-5	6	1	-2	-1	13	0	20	-8	3	38
Others	20	30	5	36	3	10	17	32	61	1	15	56	286
Total	-46	34	-2	115	23	-14	14	103	148	21	8	50	463
2013													
DE	-1	0	-8	-1	1	-1	1	-37	-3	-5	-9	-5	-68
FR	-5	0	0	1	0	-5	0	1	0	-1	4	0	-5
GB	1	0	0	-2	0	-1	0	-1	0	0	0	1	-2
IT	0	3	0	0	0	-2	0	-61	0	9	0	0	-51
ES	-1	0	0	0	1	-4	0	-68	-1	1	0	-2	-74
PL	5	0	0	0	0	-6	-11	-21	31	-3	0	1	-4
Others	-10	2	0	1	-1	-23	1	4	0	-21	-9	-1	-57
Total	-11	5	-8	-1	1	-42	-9	-183	27	-20	-14	-6	-261

2.4 The end-of-phase effect

The pattern of total exits in Figures 1 and 2 presents no obvious relationship with the concurrent evolution of industrial production in the EU, which in the years of the recession reached its minimum in 2009. We have noted, however, that the peaks of installation exits in 2007 and 2012 correspond with the final years of Phase I and Phase II of the EU ETS. We suspect that this no coincidence, as the functioning of the EU ETS de facto incentivises the postponing of already planned exits to the end of a trading phase.

This incentive may only arise for the installation operators who receive free emission allowances. For each installation for which free allowances are granted, given amounts of allowances are allocated at the beginning of a trading phase (or at the time of entry, if different) and for each year of the phase.

The allowances are handed out annually, but their initial allocation may be modified only in the cases of major expansion or reduction in the installation's production capacity. As a result, the operators of installations which for any reasons were going to exit the EU ETS may find convenient delaying the time of exit only to cash in all the allowances they had been entitled to.

Such delayed exits would entail rent transfers to operators of installations that are not economically viable, impairing the allocative efficiency of the EU ETS and thus its cost effectiveness in reducing emissions. Our data do not allow us to determine whether any of the observed exits were delayed for this particular reason. However, we can at least gauge the relevance of the question by comparing installations' emissions with the amounts of free allowances received by their operators. With reference to Phase II, Table 4 contrasts the 10^{th}, 50^{th} and 90^{th} percentiles of the allowance surpluses (allowances in excess of emissions) accumulated by two specific groups of installations operated by manufacturing firms. Namely, the installations that were in the EU ETS throughout Phase II and beyond (group A) and those that exited in 2012, the final year of Phase II (group B). The first two distributions show that the majority of all such installations accumulated significant surpluses during Phase II. However, our expectation is confirmed that these surpluses were significantly larger for the installations that exited at the end of the trading phase than for those staying in the system. With reference to the former, the 50th percentile tells us that the operators of 250 installations (50% of 499) received emission allowances in excess of actual emissions by at least 56%. The 90th percentile indicates that, in fact, the operators of 50 installations (10% of 499) received free allowances in excess of emissions by at least three and a half times (surpluses greater than 458%).

Table 4 – Allowance surpluses cumulated over Phase II: exiting vs non-exiting installations

				Installation's allowance surplus, % of emissions		
Country	Entry year, Exit year[a]	Group	Number of installations	10th percentile	50th percentile	90th percentile
All countries	Entry before/in 2008, No exit by 2012	A	4258	-7.7	25.1	149.7
	Entry before/in 2008, Exit in 2012	B	499	-7.0	56.0	458.2
DE	Entry before/in 2008, No exit by 2012	A	703	-10.6	16.6	97.6
	Entry before/in 2008, Exit in 2012	B	52	-16.4	20.0	75.2
FR	Entry before/in 2008, No exit by 2012	A	485	-6.0	26.8	125.2
	Entry before/in 2008, Exit in 2012	B	20	-1.8	84.3	281.5
GB	Entry before/in 2008, No exit by 2012	A	279	-5.1	35.5	185.8
	Entry before/in 2008, Exit in 2012	B	81	4.3	70.2	419.6
IT	Entry before/in 2008, No exit by 2012	A	515	-13.8	18.2	97.3
	Entry before/in 2008, Exit in 2012	B	50	-2.5	81.2	289.6
ES	Entry before/in 2008, No exit by 2012	A	471	-3.8	39.5	202.5
	Entry before/in 2008, Exit in 2012	B	141	49.6	178.9	952.2
PL	Entry before/in 2008, No exit by 2012	A	266	-4.4	19.8	78.3
	Entry before/in 2008, Exit in 2012	B	24	-6.4	36.9	109.0
Others	Entry before/in 2008, No exit by 2012	A	1539	-5.5	29.2	168.0
	Entry before/in 2008, Exit in 2012	B	131	-7.3	70.7	922.0

Surpluses of this magnitude are clear signs of allocative inefficiency. In Phases I and II, the allocation of allowances was under the responsibility of the national governments. The National Allocation Plans had to be designed following the criteria defined by articles 9-11 of the EU ETS Directive (2003/87/EC). The governments were left the choices of having a new entrant reserve and of continuing to give allowances for the installations closed during the trading phase. All states decided to create a new entrant reserve and almost all of them opted for the closure provision, that is, to stop giving allowances when an installation closes (Ellerman *et al.*, 2007). However, while the Directive specifies how to define a new entrant, it does not give a definition of installation closure. Thus, different governments adopted different definitions. For example, in Germany, an installation is considered closed if annual emissions are less than 10% of the reference level; in Romania, it is considered closed if both emissions and production are zero for at least one year and the installation will not be reopened. Today the allocative inefficiency problem should be less serious than it has been during the first two trading phases. As of Phase III, free allowances are distributed using common rules defined in the 2009 amending Directive (2009/29/EC). They are given ex-ante based on historical production multiplied by a sector benchmark. There is, though, an ex-post adjustment: if annual production falls below 50%, 25% or 10% of the historical production used for determining the ex-ante allocation, the allowances handed out the following year are reduced by 50%, 75% and 100%, respectively (Branger *et al.*, 2015).

3. The risk of exit: data and model

The number of installation exits observed in Phase I and Phase II of the EU ETS calls for an investigation into the relative importance of different factors explaining the risk of this event occurring. We address this question by fitting a discrete-time hazard model for the installation exit event to a micro-macro dataset assembled expressly for this study. The model is population-averaged (as opposed to subject-specific), which means unobserved heterogeneity across installations is discarded. The estimated effects thus refer to an average installation or, equivalently, a randomly drawn installation from a heterogeneous population (Xue and Brookmeyer [1997]). There follows a description of the dataset and the model.

3.1 Data

The dataset constructed for this study has a three-tier structure comprising installation-level variables, firm-level variables, and sector/economy-level variables. The EUTL, the Bureau van Dijk's ORBIS database and the Eurostat database are the original data sources.

While the EUTL offers unique information concerning the installations, it does not provide as much data which is directly usable for econometric analysis. For example, measures of an installation's size are not given. We have thus created a proxy for the measurement of this dimension. Following the approach of the European Environment Agency (EEA [2014]), the production capacity of an installation is proxied by the maximum level of its emissions observed over the years the installation participated in the EU ETS. The second variable derived from the EUTL is the number of installations operated by the same firm. The rationale for considering such a variable is that the more installations are operated by the same firm, the higher may be the chances, for each of them, to exit the EU ETS due to consolidation of production capacity at the firm level.

With the names and company identifiers of the installation operators found in the EUTL, one may retrieve information on the latter from other databases. In ORBIS, a well-known global company database, we have been able to identify a number of firms that, taken together, operate 88.5% of all installations. The coverage rises to 90% if only the installations operated by manufacturing firms are considered. These are high matching rates, but whether information on the variables of interest is available is a different matter. Indeed, the extent of data availability varies a lot across variables. ORBIS contains several variables potentially relevant to our analysis, but only some of them bear information covering sufficiently large proportions of the installations in our dataset. Among such variables, we have extracted five rendering different measures of a firm's size: operating revenue, number of employees, total assets, net income, and added value. In addition, two pairs of variables capture different dimensions of a firm's structure and economic health, respectively. The first pair includes the number of companies in the same corporate group and an indicator for listed vs non-listed companies. The other pair of variables includes a firm's profit margin and its solvency ratio[13].

[13] Among the variables discarded because of too many missing values are firms' profits, number of patents and R&D expenses.

Table 5 – Descriptive statistics of the independent variables (panel data summary)

Variable	Variable's definition	Variation component	Obs.	Mean	Std.dev.	Min	Max
gdp	Annual percentage change in GDP in country where installation *i* is located.	overall between within	N = 42115 n = 6117 T-bar = 6.88	1.07	2.92 1.48 2.63	-17.7 -6 -19.28	11 10.55 11.28
co2size	Maximum level of installation *i*'s CO_2 emissions over the years in the EU ETS. Unit: thousand tons of CO_2.	overall between within	N = 42127 n = 6119 T-bar = 6.88	156.38	553.58 498.31 0	0 0 156.38	10776.4 10776.4 156.38
instgroup	Number of active EU ETS installations operated by the firm operating installation *i*.	overall between within	N = 42127 n = 6119 T-bar = 6.88	2.79	3.73 3.93 .63	1 1 -10.54	28 28 14.34
employee	Number of employees working for the firm operating installation *i*. Unit: hundreds.	overall between within	N = 29301 n = 5255 T-bar = 5.57	36.48	201.41 173.51 26.55	.01 .01 -894.11	5728 4179.34 1585.14
listed	Dummy indicating whether the firm operating installation *i* is listed on a stock exchange.	overall between within	N = 42127 n = 6119 T-bar = 6.88	.10	.30 .29 0	0 0 .10	1 1 .10
profitmargin	Profit margin (profit before tax / operating revenue) of the firm operating installation *i*. Unit: %.	overall between within	N = 30161 n = 4598 T-bar = 6.08	3.12	15.10 12.40 10.73	-99.92 -98.49 -112.27	100 100 86.87
solvencyratio	Asset-based solvency ratio (shareholders' funds / total assets) of the firm operating installation *i*. Unit: %	overall between within	N = 32051 n = 5203 T-bar = 6.16	42.35	26.11 24.94 11.87	-99.93 -99.30 -79.24	100 100 143.07

The Eurostat database is our third data source, though the only macro variable eventually entering the model is the annual percentage change in a country's GDP. Other statistics added to our dataset are the annual percentage changes in industry electricity prices, industry gas prices, sectoral output and labour costs. Table 5 shows the definitions and the descriptive statistics of the substantive variables entering the hazard model presented in the next section. Similarly, Table A3, in the Appendix, reports the definitions and the descriptive statistics of the dependent variable for the exit event as well as those of the binary control variables for the years, sectors and countries, respectively.

3.2 A hazard model for installation exit

3.2.1 General approach

Survival analysis is the area of statistics that deals with questions relating to time duration until a given event occurs. A concept central to survival analysis is the hazard function, which sets a correspondence between the risk of event occurrence, the event not having occurred before, and time. If time during which the event may occur is measured in discrete chunks (e.g., days, weeks, years)[14], the hazard function, h, is the collection of conditional hazard probabilities across time periods:

$$h_{it} = Pr(T_i = t | T_i \geq t) \quad [1]$$

where T is a discrete random variable whose values T_i indicate the time period t when individual i experiences the event.

[14] In principle, time should be recorded in the smallest possible units relevant to the process under study.

When allowing for the possibility that different individuals may have different hazard functions, the hazard function becomes:

$$h_{it} = Pr(T_i = t | T_i \geq t;\ X_{it}) \quad [2]$$

where X_{it} is a vector of variables which may vary both across individuals and time.

The most popular approach to modeling h_{it} uses the logit transformation, which conveniently linearizes the relationship with the predictors[15]:

$$\text{logit}(h_{it}) = \alpha_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \ldots + \beta_K X_{Kit} \quad [3]$$

where α_0 and the βs are the coefficients.

Estimation of the time-discrete hazard model in [3], by Maximum Likelihood (ML), involves preliminary rearrangement of the dataset into the person-period format (see Allison [1982], or Jenkins [1995] or Singer and Willett [2003]). A person-period dataset includes a separate record for each time period when individual i – an installation, in our case – is at risk of event occurrence. In practical terms, if *i* survives three time periods, including the time of event occurrence, *i* contributes to the dataset with three records; if *i* survives six time periods, *i* contributes to the dataset with six records; and so on. An indicator variable, Y_{it}, takes the value 1 if *i* experiences the target event in time period *t*, and 0 otherwise. The model coefficients are then estimated by maximizing the log-likelihood function:

$$LL = \sum_{i=1}^{n} \sum_{t=1}^{T_i} Y_{it} \ln(h_{it}) + (1 - Y_{it}) \ln(1 - h_{it}) \quad [4]$$

where individual *i* contributes h_{it} if $Y_{it} = 1$ and $(1 - h_{it})$ if $Y_{it} = 0$ (hence, in all previous T_i-*1* time periods).

In our application below, $exit_{it}$ is the observed binary outcome (Y_{it} in [4]) indicating whether installation *i* exited in year *t* ($exit_{it} = 1$) or stayed in the system ($exit_{it} = 0$).

3.2.2 Model specification

We here present our population-averaged discrete-time hazard model for the event of an installation exiting the EU ETS. The relevant population is the ensemble of all the EU ETS installations operated by manufacturing firms. The model is fitted to a subset of the micro-macro dataset above described, spanning the nine-year period 2005-2013.

The model specification that only includes the set of dummy variables for the sample years (d_{2005}, d_{2006}, …, d_{2013}) provides the so-called baseline hazard function, which renders the time-dependency of the hazard rate. The model is then augmented with additional binary control variables and a number of substantive predictors (chosen among those for which sufficient data are available). With reference to the first, the following enter the model:

a) A set of dummies for the sectors (12) of the firms operating the installations (s_1, s_2, …, s_{12});
b) A set of dummies for the countries (29) where the installations are located (c_1, c_2, …, c_{29}).

As to the substantive predictors, those entering the best-fitting model are (see Table 5 for the definitions and the descriptive statistics):

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[15] Logit is the natural logarithm of the odds of event occurrence. That is, logit $(h_{it}) \equiv \ln[h_{it}/(1 - h_{it})]$.

c) The average growth rate of the economy (GDP) in the current and the previous year, in the country where the installation is located (*econgrowth*)[16];
d) The size (production capacity) of the installation, proxied by the maximum level of its observed emissions (*co2size*);
e) The number of installations operated by the same firm (*instgroup*);
f) The number of employees of the firm operating the installation (*employee*);
g) A dummy indicating whether the firm operating the installation is a listed company (*listed*);
h) The profitability of the firm operating the installation (*profitmargin*);
i) The solvency capacity of the firm operating the installation (*solvencyratio*).

Annual percentage variations in the indices of sectoral output, industry electricity prices, industry gas prices and labour costs have been considered, but their estimated effects were either statistically non-significant or plausibly spurious[17]. Additional firm-level variables have also been tested, but either their effects are non-significant[18] or too many missing values mean the sample shrinks excessively.

To avoid potential simultaneity bias issues, one-year lags are used for the relevant installation- and firm-level variables. This comes with a cost: all observations from the first year are lost, as the ORBIS data on firm-level variables are not available for the years before 2005. The resulting specification of the hazard model for the exit of an installation is thus the following:

$$\text{logit}\,(h_{it}) = \mu + \sum_{j=2007}^{2013} \alpha_j d_{ji} + \sum_{k=2}^{12} \delta_k s_{ki} + \sum_{l=2}^{29} \lambda_l c_{li} + \theta econgrowth_{it} + \beta co2size_{it-1}$$
$$+ \gamma_1 instgroup_{it-1} + \gamma_2 employee_{it-1} + \gamma_3 listed_i + \gamma_4 profitmargin_{it-1}$$
$$+ \gamma_5 solvencyratio_{it-1} \qquad [5]$$

where: h_{it} is the probability of exit, this event not having occurred before; the explanatory variables are defined as above; and the γ coefficients specifically denote firm-level variables.

As concerns the model estimation, the ML estimator used is robust to potential correlation between the installations operated by the same firm.

4. Estimation results

Table 6 shows the estimation results for the hazard model in [5] (M6) and for five of its nested versions (M1-M5). Contrasting the six sets of results allows us to better appreciate the contributions of the different variables to the final model's fitting[19]. The coefficients presented are exponentiated, implying they represent multiplicative effects of a unit increase in the predictor on the event's odds ratio[20]. That is, for a given estimated coefficient $\hat{\beta}_k$,

[16] To allow for possible prolonged effects of the economic context on an installation's exit, we averaged the current GDP growth rate, gdp_t, with those of the previous years (up to three). The variable constructed as the simple average of gdp_t and gdp_{t-1} ($econgrowth_t = 0.5(gdp_{t-1} + gdp_t)$) turned out to fit the data best.

[17] This is the case of natural gas prices, which turned out to be negatively correlated with installation exits.

[18] Notably, the measures of a firm's size which are alternative to *employee* are highly correlated with one another.

[19] The results are directly comparable across the regressions, as they are based on an identical sample: one of 22266 observations (N), covering 4293 installations (n).

[20] The estimated (non-exponentiated) coefficients of the most comprehensive model version M6, the respective 95% confidence intervals and p-values, are reported in Table A4, in the Appendix.

$$e^{\widehat{\beta}_k} = \frac{(\hat{h}|\ x_k + 1)/[1 - (\hat{h}|\ x_k + 1)]}{(\hat{h}|\ x_k)/[1 - (\hat{h}|\ x_k)]}$$

[6]

Thus, an exponentiated coefficient not significantly different from 1 indicates that an increase in the relative predictor has no significant effect on the likelihood of event occurrence. By the same token, $e^{\widehat{\beta}_k}$ greater (smaller) than 1 indicates that $\Delta x_k > 0$ has a positive (negative) effect on the likelihood of the event occurring.

The first model version, M1, only includes the set of dummies for the sample years. Relative to 2006, which is the reference year[21], the chances of exit turn out to be significantly higher in 2007 and 2012 and, conversely, significantly lower in 2010 and 2013. The effects are quantified as multiplying the odds of exit in 2006 by 2.2 (i.e., the odds more than double) and by 2.0 in 2007 and 2012, respectively, and by 0.6 and 0.5 in 2010 and 2013. These effects are generally stable across the different model versions. The latter two are non-significant in M2, controlling both for sectoral and country effects, but they revert to being significant after controlling for the growth rate of the economy in the other more comprehensive model versions. The 2007 and 2012 effects reflect the observed pattern of total installation exits, which have been shown to be clearly more numerous in these two years (Figures 1 and 2). The end-of-phase effect, explained with the implicit incentive to procrastinate exit till the end of the trading phase (Section 2.4), is thus confirmed after controlling for a number of other relevant factors.

Table 6 – Estimation results, exponentiated coefficients (odds ratios)

	M1	M2	M3	M4	M5	M6
d:2007	2.2127***	2.3910***	2.5771***	2.5783***	2.6547***	2.6396***
d:2008	1.2394	1.4335**	1.3114	1.3167	1.3476*	1.4015*
d:2009	1.1967	1.5000**	0.8469	0.8472	0.8537	0.8602
d:2010	0.6328**	0.7785	0.4669***	0.4683***	0.4793***	0.4720***
d:2011	0.6937*	0.8594	0.7378	0.7408	0.7707	0.7559
d:2012	2.0835***	2.6442***	1.9682***	1.9804***	2.0638***	2.0500***
d:2013	0.5628**	0.7064	0.4777***	0.4819***	0.5026***	0.5000***
s:Textiles		1.8134***	1.8176***	1.7793***	1.9884***	1.8044***
s:Wood		1.1805	1.1767	1.1622	1.2434	1.1495
s:Paper		0.6748**	0.6749**	0.6900**	0.7334**	0.7329**
s:Coke and petroleum prod.		0.5106**	0.5096**	0.9871	1.0928	1.0899
s:Chemicals		0.6048***	0.6017***	0.6542**	0.7187**	0.7502*
s:Glass		0.3611***	0.3623***	0.3740***	0.3889***	0.4263***
s:Bricks		0.9753	0.9747	0.9629	0.8598	0.8595
s:Ceramics		15.4088***	15.7903***	15.5042***	16.2966***	16.6012***
s:Cement		0.5634***	0.5619***	0.7715	0.7574	0.8571
s:Metals		0.6583*	0.6597*	0.7935	0.8550	0.8334
s:Other manufacturing		1.2992	1.2958	1.2737	1.5409**	1.3680*
c:CY		3.0650***	3.1366***	5.0445***	5.1615***	6.8577***
c:CZ		0.5925**	0.6548*	0.6359*	0.6783	0.8236
c:ES		0.7335*	0.6690**	0.6535**	0.7822	0.8266
c:FR		0.5761***	0.5225***	0.5136***	0.5462***	0.5725***
c:GR		0.5984	0.4312*	0.4209*	0.4783*	0.4557*
c:IE		2.2751*	2.1248*	2.1597*	2.6912**	2.4622**
c:IT		0.8056	0.6412**	0.6202**	0.6717**	0.6797**
c:SE		0.5777*	0.5892	0.5556*	0.6265	0.7222
c:SI		0.4698*	0.4694*	0.4351**	0.4867*	0.5328

[21] For a given set of dummies, the reference (or base) category corresponds to the dummy omitted to avoid perfect multicollinearity.

c:SK		1.5215	2.1439**	2.1532**	2.4359***	2.4426***
econgrowth			0.8887***	0.8883***	0.8882***	0.9023***
co2size				0.9989*	0.9988*	0.9988*
instgroup					1.0447***	1.0468***
employee					0.9993**	0.9994**
listed					1.2344	1.3353**
profitmargin						0.9869***
solvencyratio						0.9919***
constant	0.0284***	0.0329***	0.0494***	0.0523***	0.0397***	0.0514***
Observations (N)	22666	22666	22666	22666	22666	22666
Installations (n)	4293	4293	4293	4293	4293	4293
Log-likelihood	-3188.8818	-3007.9302	-3001.9154	-2986.2626	-2970.3963	-2935.3965
Pseudo-R^2	0.0259	0.0812	0.0830	0.0878	0.0926	0.1033
AIC	6393.7635	6099.8604	6089.8308	6060.5251	6034.7926	5968.7931

Note: p-value: * < .1; ** < .05; *** < .01.

The inclusion of both sectoral and country controls, in M2, greatly improves the model's fitting, as shown by the Pseudo-R^2 passing from .02 to .08. Relative to an average installation operated by a firm in the *Food* sector, the reference sector, the odds of exiting the EU ETS for a randomly drawn installation operated by a firm in the *Ceramics* sector are about 15 times as high. Such a large effect reflects the observed rapid shrinkage of the *Ceramics* sector in terms of number of installations, a phenomenon more pronounced than for any of the other sectors[22]. The only other sector with an odds ratio significantly greater than 1 in all the model versions, though of a much smaller magnitude (about 1.8), is the *Textiles* sector. A long-term trend of competitiveness deterioration (unrelated to carbon regulation) underlies this particular effect. By contrast, the chances of exit are substantially lower for installations operated by firms in the *Glass* sector and in the *Paper* sector. The respective odds are on average about 60% and 30% lower than for installations operated by firms in the reference *Food* sector. For space reasons, Table 6 only reports results for the country dummies whose effects are found statistically significant in at least one of the model versions. Relative to an average installation located in Germany, the reference country, the odds of exiting the EU ETS are significantly higher for randomly drawn installations located in Cyprus, Ireland and Slovakia. Viceversa, the odds are lower for installations in Greece, France and Italy. What factors underlie these effects may be a question worth exploring. The introduction of a variable measuring the growth rate of the economy in the country where the installation is located (*econgrowth*) characterizes M3. The economic context is found to have a significant effect on the likelihood of an installation exiting the EU ETS, as one would expect. Controlling for economic growth also proves to be important in relation to the identification of the baseline hazard function rendered through the set of year dummies. For example, year 2009, corresponding to the peak of the economic crisis, ceases to be riskier than 2006, the base year, after *econgrowth* enters the equation.

The model version M4 introduces the only installation-level variable accounted for in our analysis (*co2size*). The size of an installation, proxied by the maximum level of its observed emissions, turns out to have a negative effect on the chances of exit, though only at the .1 significance level. A negative effect is indeed expected based on the presumption that bigger plants are more costly to close down and that they are less likely to see their capacity reduced below the minimum threshold. The odds ratio obtained indicates that a difference in production capacity proxied by 1,000 tons of CO_2 emissions per year adjusts the odds of an installation exiting by 1%. Detailing the model further, three firm-level variables are introduced by M5: the total number of EU ETS installations operated (*instgroup*), the total number of employees (*employee*) and a dummy indicating whether the firm is a listed company

[22] Tables 2 and 3 report the numbers of installations and installation exits, respectively.

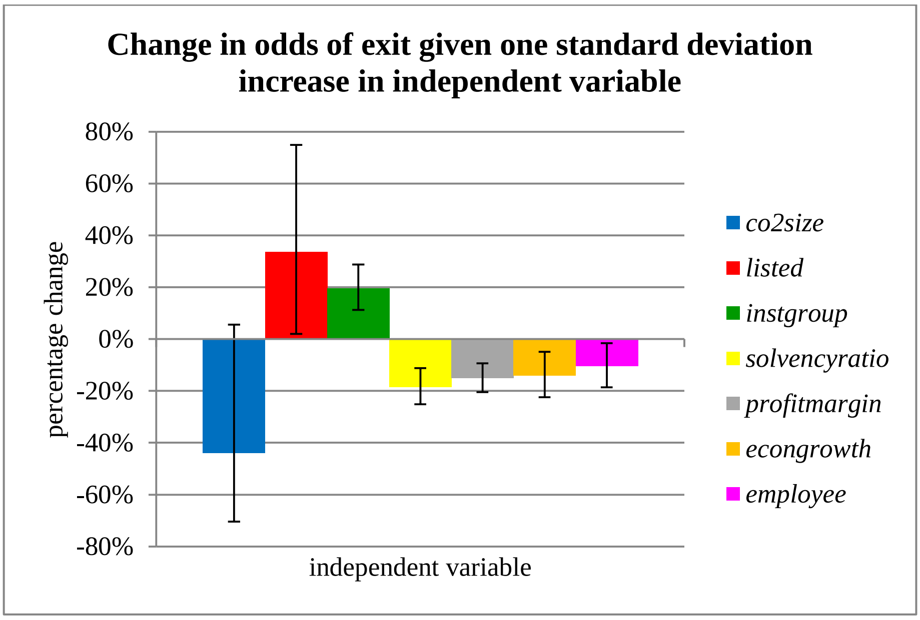
(*listed*). The first effect is positive and highly significant. This is consistent with the hypothesis that firms may consolidate their production capacity by closing down some of the installations they operate. In quantitative terms, one extra installation increases the odds of exit for each of the other installations operated by the same firm by about 4.5%. Conversely, installations operated by firms with a larger number of employees are less likely to exit. Nevertheless, the chances to exit are higher for installations operated by listed companies. Such an effect, statistically significant in M6 (not in M5), may be a hint of a correlation between diffused ownership and the mobility of productive capital. Finally, the model version M6 brings in direct measures of the profitability (*profitmargin*) and the solvency capacity (*solvencyratio*) of the firm operating the installation. Both effects are significant and have the expected sign: the likelihood of an installation exiting decreases with the improved economic and financial health of the relative firm.

To appreciate the relative importance of the different factors affecting the likelihood of an installation exiting the EU ETS, we compare the effects of plausible variations in the respective variables. We first take to be plausible the variations equal to one standard deviation of the installation-level sample means. That is, with reference to Table 5, we consider variations (Δx_k) equal to the standard deviations between installations (498.31 for *co2size*, 3.93 for *instgroup*, etc.). The respective effects are then derived as percentage changes in the odds of exit:

$$e^{(\hat{\beta}_k \Delta x_k)} - 1 = \frac{\{(\hat{h}|\, x_k + \Delta x_k)/[1-(\hat{h}|\, x_k + \Delta x_k)]\} - (\hat{h}|\, x_k)/[1-(\hat{h}|\, x_k)]}{(\hat{h}|\, x_k)/[1-(\hat{h}|\, x_k)]} \quad [7]$$

Figure 3 shows the effects thus derived for positive variations ($\Delta x_k > 0$) in the substantive variables entering M6. The two largest effects are observed for the greater size of an installation (*co2size*) and for the status of a firm as a listed company relative to a non-listed one (*listed*). The first effect is an average 40% reduction in the odds of exit. The second effect amounts to an average 30% increase. However, uncertainty concerning both of these effects is quite high, which is the consequence of wide confidence intervals for the respective estimated coefficients (Table A2, in the Appendix). Smaller but more accurately identified effects are found for the other remaining variables.

Fig. 3 – Effects comparison of one standard deviation increase in independent variables.



Note: The error bars represent 95% confidence intervals.

5. Conclusions

A pessimistic view of the EU ETS is that the carbon costs burdening the firms operating in the regulated sectors will eventually result in the relocation of some production activities to countries imposing lower carbon costs. To date, no empirical studies have investigated whether this phenomenon known as investment leakage has been taking place. Answering this question implies identifying a statistically significant effect whereby the EU ETS causes the relocation of certain production activities. This paper brings evidence relevant to investment leakage in the industrial sector of the EU ETS, although it is not concerned with the identification of investment leakage. The first part of the analysis consists in ascertaining whether, where (in which countries and sectors) and to what extent the exits of installations operated by manufacturing firms have outnumbered the entries. By fitting a discrete-time hazard model to a suitable micro-macro dataset, we subsequently identify a number of variables (both time-invariant and time-varying) explaining the risk of an installation exiting the EU ETS. The results obtained and some methodological aspects of the study (e.g., the rules for the identification of exits and entries) may be useful for future attempts to identify investment leakage.

The original contribution of this paper to the literature is twofold. In the first place, it is the first study to systematically identify installation entries and exits into and from the EU ETS. The patterns identified indeed constitute a novel piece of evidence concerning the past development of the EU ETS. Secondly, it is the first study to estimate a model for the risk of an installation exiting the EU ETS. Concerning the findings, the results of the descriptive analysis show that the number of exits has been remarkable relative to the number of installations. What is more, there have been significantly more exits than entries, especially considering that some of the entries are merely the consequence of occasional regulatory changes in the implementation of the EU ETS at the national level. A question worth exploring in the future would then be whether this imbalance is entirely explained by the economic crisis which has hit hard the EU's manufacturing sector in the last few years. Moreover, in terms of number of regulated installations, the sector that by far has shrunk more than the others is the *Ceramics* sector. Here, the very large number of installation exits observed in Germany suggests that – perhaps – the exits due to capacity reduction (rather than those due to the shutdown of the installation) might be more frequent than one would expect.

The estimated hazard model identifies a number of different effects which generally meet the expectations. The likelihood of an installation exiting the EU ETS is found to be negatively related to the capacity of the installation (proxied by the maximum emissions level), the economic and financial health of the firm, the size of the firm (measured by the number of employees) and the growth rate of the economy in the country where the installation is located; conversely, it is positively related to the status of the firm as a listed company and the number of installations operated by the same firm. However, arguably the most interesting of the effects identified is one that reveals a limitation in the working of the EU ETS in its first two trading phases. Namely, we find that the chances of exit were significantly higher in the final years of the Phases I and II than at different times. This "end-of-phase effect" is interpreted as being the consequence of an implicit incentive to postpone already planned installation exits to the end of the current trading phase. Such an incentive, which stems from the rules concerning the closure of an installation and the withdrawal of the relative emission allowances, is detrimental to the allocative efficiency of the system and, therefore, to its cost-effectiveness in emissions abatement.

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Appendix

Table A1 – Correspondence between the NACE Rev2 classification and the NACE-based sectors

NACE-based sector	NACE Rev2			Description of NACE sector
	1 digit	2 digit	3 digit	
Food	C	10		Food products
	C	11		Beverages
	C	12		Tobacco products
Textiles	C	13		Textiles
	C	14		Wearing apparel
	C	15		Leather and related products
Wood	C	16		Wood, wood products, straw articles, plaiting materials
Paper	C	17		Paper, paper products
	C	18		Printing, reproduction of recorded media
Coke and petroleum prod.	C	19		Coke, refined petroleum products
Chemicals	C	20		Chemicals, chemical products
	C	21		Pharmaceutical products and preparations
	C	22		Rubber, plastic products
Glass	C	23	23.1	Glass, glass products
Bricks	C	23	23.2	Refractory products
	C	23	23.3	Clay building materials
Ceramics	C	23	23.4	Other porcelain and ceramic products
Cement	C	23	23.5	Cement, lime and plaster
	C	23	23.6	Articles of concrete, cement and plaster
	C	23	23.9	Abrasive products and non-metallic mineral prod. n.e.c.
Metals	C	24		Basic metals
Other manufacturing	C	25		Fabricated metal prod. (except machinery and equipm.)
	C	26		Computer, electronic and optical products
	C	27		Electrical equipment
	C	28		Machinery and equipment n.e.c.
	C	29		Motor vehicles, trailers and semi-trailers
	C	30		Other transport equipment
	C	31		Furniture
	C	32		Other manufacturing
	C	33		Repair and installation of machinery and equipment
Non-manufacturing	≠ C			Non-manufacturing activities

Table A2 – Installations (with positive VE in at least one year between 2005 and 2012) operated by manufacturing firms, by EU ETS sector and NACE-based sector

	NACE-based sector (firm-level)												
EU ETS sector (installation-level)	Food	Textiles	Wood	Paper	Coke and petr. prod.	Chemicals	Glass	Bricks	Ceramics	Cement	Metals	Other manuf.	Total
Combustion of fuels	1027	134	144	96	23	707	4	20	12	78	116	343	2704
Refining of mineral oil	2	0	0	0	153	1	0	0	0	0	0	1	157
Prod. of coke	0	0	0	0	19	0	0	0	0	1	2	0	22
Metal ore roasting or sintering	0	0	0	0	0	0	0	0	0	0	4	0	4
Prod. of pig iron or steel	0	0	0	0	2	1	0	0	0	0	253	5	261
Prod./process. of ferrous metals	0	0	0	0	0	0	0	0	0	0	27	1	28
Prod. of primary aluminium	0	0	0	0	0	0	0	0	0	0	4	0	4
Prod. of secondary aluminium	0	0	0	0	0	0	0	1	0	0	1	0	2
Prod./process. of nonferrous metals	0	0	0	0	0	0	0	0	0	0	3	0	3
Prod. of cement clinker	22	0	0	3	0	0	0	3	0	392	0	0	420
Prod. of lime, calcination of dolomite/magn.	24	0	0	0	0	1	0	7	0	132	0	0	164
Manuf. of glass	0	0	1	0	0	26	398	1	1	5	0	1	433
Manuf. of ceramics	1	1	1	0	0	1	2	1016	212	26	1	0	1261
Manuf. of mineral wool	0	0	0	0	0	0	5	0	0	14	0	0	19
Prod./process. of gypsum or plasterboard	0	0	0	0	0	0	0	0	0	10	0	0	10
Prod. of pulp	0	1	0	93	0	2	1	0	0	0	0	0	97
Prod. of paper or cardboard	0	2	3	786	0	0	0	0	0	0	0	0	791
Prod. of carbon black	0	0	0	0	0	7	0	0	0	0	0	0	7
Prod. of nitric acid	0	0	0	0	0	3	0	0	0	0	0	0	3
Prod. of ammonia	0	0	0	0	0	4	0	0	0	0	0	0	4
Prod. of bulk chemicals	0	0	0	0	0	39	0	0	0	0	0	0	39
Prod. of soda ash and sodium bicarbonate	0	0	0	0	0	1	0	0	0	0	0	0	1
Other activity opted-in	7	2	4	3	1	21	1	4	0	5	11	7	66
Total	1083	140	153	981	198	814	411	1052	225	663	422	358	6500

Note: See EEA (2014) on harmonization of old and new sector labels in the EUTL

Table A3 – Descriptive statistics of the dependent variable and the sets of year-, sector- and country controls

Variable	Variable's definition	Obs.	Mean	Std.dev.	Min	Max
exit	Dummy for installation exit event (dependent variable): $exit_{it}$ = 1 if installation *i* exits in year *t*; $exit_{it}$ = 0 otherwise.	42127	.0344	.1824	0	1
d:2005	Dummy for year 2005: d_2005_i = 1 if installation *i* is observed in year 2005; d_2005_i = 0 otherwise.	42127	.1116	.3148	0	1
d:2006	Dummy for year 2006.	42127	.1135	.3172	0	1
d:2007	Dummy for year 2007.	42127	.1131	.3167	0	1
d:2008	Dummy for year 2008.	42127	.1174	.3219	0	1
d:2009	Dummy for year 2009.	42127	.1141	.3179	0	1
d:2010	Dummy for year 2010.	42127	.1116	.3148	0	1
d:2011	Dummy for year 2011.	42127	.1096	.3124	0	1
d:2012	Dummy for year 2012.	42127	.1064	.3084	0	1
d:2013	Dummy for year 2013.	42127	.1023	.3031	0	1
s:Food	Dummy for Food sector: s_food_i = 1 if installation *i* is operated by a firm in the *Food* (NACE-based) sector; s_food_i = 0 otherwise.	42127	.1625	.3689	0	1
s:Textiles	Dummy for Textiles sector.	42127	.0190	.1367	0	1
s:Wood	Dummy for Wood sector.	42127	.0240	.1532	0	1
s:Paper	Dummy for Paper sector.	42127	.1593	.3659	0	1
s:Coke & petr.pr.	Dummy for Coke and petroleum prod. sector.	42127	.0340	.1813	0	1
s:Chemicals	Dummy for Chemicals sector.	42127	.1298	.3361	0	1
s:Glass	Dummy for Glass sector.	42127	.0702	.2555	0	1
s:Bricks	Dummy for Bricks sector.	42127	.1636	.3699	0	1
s:Ceramics	Dummy for Ceramics sector.	42127	.0143	.1190	0	1
s:Cement	Dummy for Cement sector.	42127	.1078	.3102	0	1
s:Metals	Dummy for Metals sector.	42127	.0612	.2398	0	1
s:Other manuf.	Dummy for Other manufacturing sector.	42127	.0536	.2253	0	1
c:DE	Dummy for Germany: c_DE_i = 1 if installation *i* is located in Germany; c_DE_i = 0 otherwise.	42127	.1732	.3784	0	1
c:FR	Dummy for France.	42127	.1096	.3124	0	1
c:UK	Dummy for UK.	42127	.0666	.2494	0	1
c:IT	Dummy for Italy.	42127	.1207	.3258	0	1
c:ES	Dummy for Spain.	42127	.1330	.3396	0	1
c:PL	Dummy for Poland.	42127	.0610	.2393	0	1
c:Others	Dummy for all other countries.	42127	.3355	.4721	0	1

Note: Dummies for each single country enter the model. For space reasons, this table only reports the descriptive statistics for the dummies of the six Member States with the largest number of installations and for the group of all the remaining countries.

Table A4 – Estimation results of M6

	Coeff.	Std. error	Z	P > |z|	95% Confidence interval	
d:2007	0.9706	0.1626	5.97	0.000	0.6519	1.2894
d:2008	0.3375	0.1781	1.89	0.058	-0.0116	0.6867
d:2009	-0.1506	0.2346	-0.64	0.521	-0.6104	0.3093
d:2010	-0.7508	0.2410	-3.12	0.002	-1.2230	-0.2785
d:2011	-0.2798	0.1937	-1.44	0.149	-0.6594	0.0998
d:2012	0.7178	0.1977	3.63	0.000	0.3304	1.1053
d:2013	-0.6932	0.2620	-2.65	0.008	-1.2066	-0.1797
s:Textiles	0.5903	0.2216	2.66	0.008	0.1559	1.0246
s:Wood	0.1394	0.2328	0.60	0.550	-0.3170	0.5957
s:Paper	-0.3108	0.1502	-2.07	0.039	-0.6052	-0.0164
s:Coke and petroleum prod.	0.0861	0.3563	0.24	0.809	-0.6123	0.7845
s:Chemicals	-0.2874	0.1597	-1.80	0.072	-0.6004	0.0256
s:Glass	-0.8526	0.2346	-3.63	0.000	-1.3124	-0.3927
s:Bricks	-0.1515	0.1443	-1.05	0.294	-0.4343	0.1314
s:Ceramics	2.8095	0.2621	10.72	0.000	2.2958	3.3231
s:Cement	-0.1542	0.2382	-0.65	0.517	-0.6212	0.3128
s:Metals	-0.1823	0.2117	-0.86	0.389	-0.5971	0.2326
s:Other manufacturing	0.3133	0.1854	1.69	0.091	-0.0501	0.6768
c:CY	1.9254	0.3355	5.74	0.000	1.2678	2.5829
c:FR	-0.5578	0.2050	-2.72	0.007	-0.9595	-0.1560
c:GR	-0.7860	0.4354	-1.81	0.071	-1.6393	0.0673
c:IE	0.9010	0.4436	2.03	0.042	0.0316	1.7704
c:IT	-0.3862	0.1944	-1.99	0.047	-0.7671	-0.0052
c:SK	0.8930	0.3011	2.97	0.003	0.3029	1.4832
econgrowth	-0.1028	0.0353	-2.91	0.004	-0.1719	-0.0336
co2size	-0.0012	0.0007	-1.79	0.073	-0.0024	0.0001
instgroup	0.0457	0.0095	4.82	0.000	0.0271	0.0643
employee	-0.0006	0.0003	-2.29	0.022	-0.0012	-0.0001
listed	0.2891	0.1376	2.10	0.036	0.0194	0.5588
profitmargin	-0.0131	0.0027	-4.90	0.000	-0.0184	-0.0079
solvencyratio	-0.0082	0.0017	-4.68	0.000	-0.0116	-0.0047
constant	-2.96856	0.233446	-12.72	0.000	-3.4261	-2.51101
Observations (N)	22666					
Installations (n)	4293					
Log-likelihood	-2935.3965					
Pseudo-R^2	0.1033					
AIC	5968.7931					

Note: For space reasons, only country effects that are statistically significant are reported.

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