www.energy-evaluation.org
ENERGY EVALUATION EUROPE
2021 Virtual Conference
Wednesday 10 – Thursday 11 and
Monday 15 – Tuesday 16 March 2021
Formerly IEPPEC
Accelerating the energy transition for all: Evaluation's role in effective policy making

A Comparative Analysis of the Trading Behavior of the Participants in the first three Phases of the EU Emissions Trading System

Thomas Leu, Zurich University of Applied Sciences, Switzerland (thomas.leu@zhaw.ch)

ABSTRACT

The European Union emissions trading systems EU ETS in the third phase (2013-2020) differs significantly from the first phase. The emissions cap is now EU-wide in place of national caps, whereas auctioning is the default method for allocating allowances instead of the free allocations. The aim of this paper is to empirically quantify the changes in the allowance trading behavior between the first, the second and the third phase of the EU ETS. European Union transaction log data from the first and the second trading phase is matched with the years 2013-2014 from the third period. The question to be answered here is whether, holding constant other factors, trading behavior has changed. In a first step, by descriptive statistics, differences of the trading behavior between the first and the third trading phase are identified by comparing firms with an allocation surplus with firms with no allocation surplus. In a second step, binary choice regression models with panel data are used to figure out the determinants of the propensity to engage in trading. The increase in trading participation between these three phases is mainly based on a reduction of the allocation cap, the auctioning of a part of the allowances instead of free allocation and learning effects. In a third step the opportunity costs of those firms that do not sell their allocation surplus are quantified by directly using the data of the European Union Transaction Log linked with annual average transaction price data. This approach is novel in the literature. The results show that the overall opportunity costs of non-trading are decreasing between the first and the third phase.

1 Introduction

The European Union emissions trading system (EU ETS) has been operational since 2005 and is the world's largest emissions trading system. In 2021 the fourth phase (2021-2030) has begun. Compared to phase three (2013-2020) the emissions cap will decrease by 2.2% every year instead of 1.74%. The EU ETS covers around 40% of the greenhouse gas emissions from more than 11,000 stationary installations and airlines in the participating countries. In Figure 1.1 EU ETS participants are grouped by their size category in 2019.

The size of the installations is usually measured as maximum verified emissions over a certain time span. Installations with less than 25,000 tons of CO_2eq emissions per year dominate with a share of around 60% (see Figure 1.1, left graph). However, the distribution of the verified emissions shows that 75% of the emissions originate from large plants that emit more than 500,000 tons of CO_2eq (see Figure 1.1, right graph). The size has implications on the trading behavior of the participating firms analyzed in this paper. It might be the case that smaller entities have less opportunities to exploit economies of scale and are, therefore, less engaged in trading activities, especially in the first phase of the EU ETS when the trading of emissions allowances was novel for most of the participants.

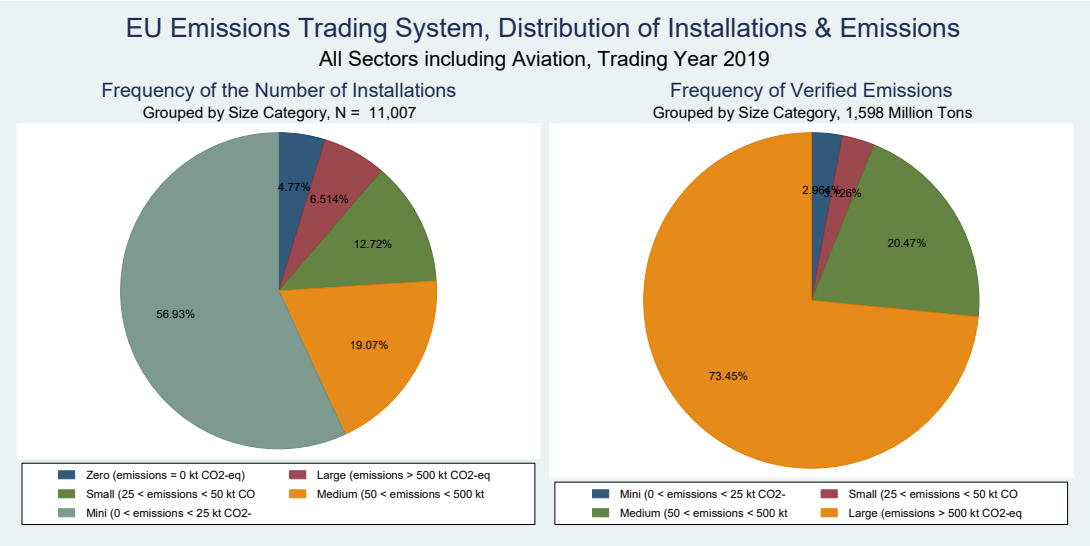


Figure 1.1. Pie chart of the relative frequencies of the distribution of the number of installations (left graph) and the verified emissions (right graph).

Note: Own calculation based on the data source from the European Environment Agency (EEA). The size category is taken from the EEA.

From phase to phase the EU ETS has been revised. These revisions might have an impact on trading behavior of the participants. In the first phase of the EU ETS (2005-2007) emissions allowances were allocated freely to the participating installations based on historic emissions (grandfathering). The overall EU-wide cap of allowances was set bottom-up through national allocations plans. It became apparent that the allocation of the emission allowances was higher than the effective emissions[1]. These excess allocations lead to a sharp price drop towards zero at the end of phase I since excess allowances could not be banked into the second phase (2008-2012).

The most important revision is the introduction of auctions instead of grandfathering beginning in phase II (2008-2012). In phase II, however, free allocation was still 90%. In phase III (2013-2020), the method for allocating allowances has started to change from free allocation to an auctioning system. As a result, 57% of the allocations was auctioned in phase III. For phase IV (2021-2030) it is planned that auctioning is going to be the default method. However, the share of allowances to be auctioned remains the same as in phase III[2]. This can be seen graphically in Figure 1.2. The upper graph shows how allowances were allocated to the installations from the first trading year 2005 until 2019. From 2008 onwards, the vertical bars are subdivided into free allocation or auctioned and sold allocation. It is obvious that from the beginning of phase III, the share of auctions has been rising substantially[3].

[1] See Website of the European Union Emissions Trading scheme: https://ec.europa.eu/clima/policies/ets/pre2013_en

[2] For detailed information about the institutional settings and the development of the EU ETS refer to the corresponding directive (European Union, 2003), the Commission regulation (European Union, 2013), the EU ETS handbook (European Union, 2015) and Website of the European Commission: https://ec.europa.eu/clima/policies/ets_en

[3] A summary of the most important revisions is presented in Table 2.1.

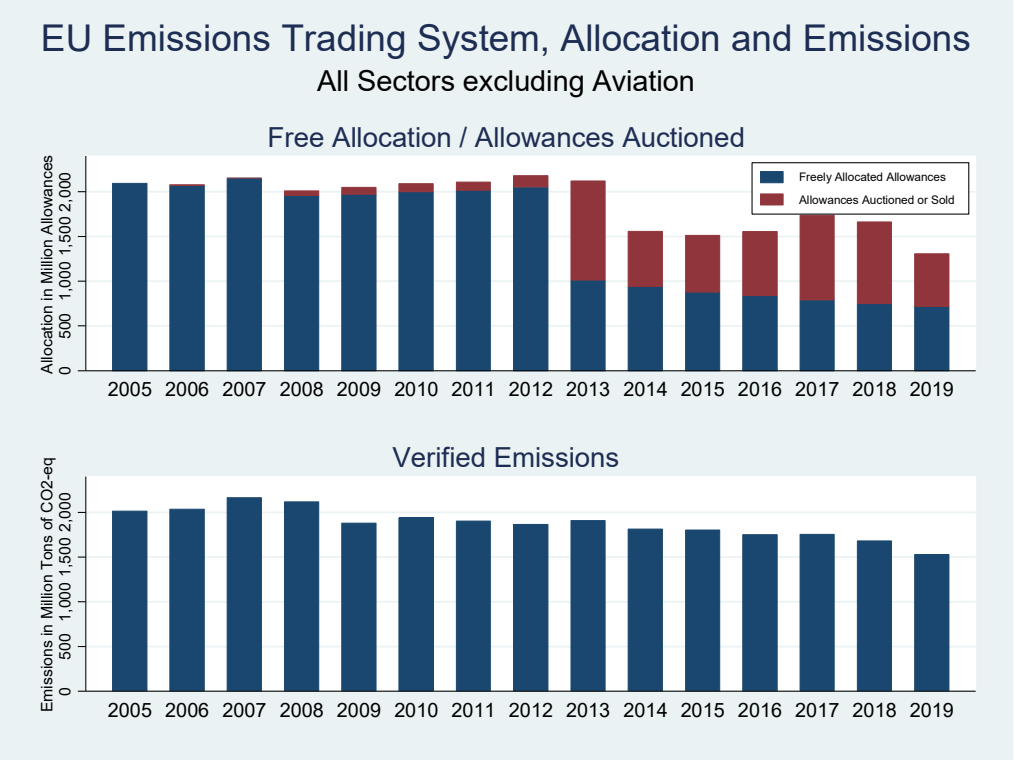


Figure 1.2. Evolution of the allowance allocation grouped by freely or sold allowances (upper graph) and the verified emissions (bottom graph).

Note: Own calculation based on the data source from the European Environment Agency (EEA). Phase I (2005-2007): Cap on allowances according to national allocation plans, free allocation is the default, allowances could not be banked to phase II. Phase II (2008-2012): Cap on allowances 6.5% lower compared to 2005, free allocation around 90%, allowances could be banked to phase to phase III. Phase III (2013-2020): Union-wide cap for stationary installations decreases by 1.74% every year, 57% of the allowances were auctioned.

The ongoing reduction of the emissions cap heightens the pressure on the installations to increase abatement efforts. This fact should, in theory, increase the demand side of the carbon market. Higher carbon prices increase the opportunity costs of holding excess allowances, which should be reflected on the supply side. Therefore, these drivers could explain the higher trading activities on the EUA allowance market. According to Montgomery (1972) market based instruments equalize marginal abatement costs and lead to cost efficient results compared to a situation where just the pollution level is equalized. In the presence of transaction costs, however, the price received by the seller is lower and the price paid by the buyer is higher than the price without transaction costs. The traded volume is lower than the efficient trading level leading to an efficiency loss. In his seminal paper Stavins (1995) has elaborated the theoretical basis for the emissions trading market in the presence of transaction costs. He holds that one needs to be careful with the instrument design of an emissions trading system since transaction costs could lead to substantial efficiency losses.

Literature on the amount of transaction costs is found especially for phase I since, as my research in section 5 shows, in phase I trading costs could have been the reason for many firms not engaging in trading their allowance surplus. Table 1.1 summarizes these studies.

Table 1.1. Previous Transaction Cost Estimates.

Study	TC Definition	Results
Behringer et al. (2006)	Application for allowances, IT, MRV, external consulting, and other costs of 31 German firms	€ 0.1/tCO_2 (large companies), € 0.43/tCO_2 (small companies), up to € 3.2/tCO_2 (Ceramics)
Graus and Voogt (2007)	Survey of EU member states, TC of small installations	€ 1'400 - 21'500 per installation and year
Jaraitė et al. (2010)	Transaction costs of 27 surveyed Irish firms	€ 0.05/tCO_2 (large companies), € 2.02/tCO_2 (small companies) EU ETS Phase I overall € 3.8 million (of which € 2.0 million setting up and € 1.8 million MRV/year)
Betz et al. (2010)	Trading costs only include costs for intermediary	Strategy: € 5'000 - 12'000 (small - large), MRV: € 12'000 - 66'000, Trading: € 0.025 - 0.006/tCO_2
Heindl (2012)	TC of 150 German firms: MRV, Trading, Strategy	up to €1 /tCO_2, € 8.7 Mio/year in Germany

Note: MRV is the annual process of monitoring, reporting and verification the emissions.

Literature on trading behavior in the EU ETS is found also for phases I and phases II. The paper of Jaraitė-Kažukauskė and Kažukauskas (2015) analyses in detail firms' trading behavior in the first phase of the EU ETS. They identify determinants of the participation in the emissions market. Relevant insights are further elaborated by Martin et al. (2014). In addition to Jaraitė-Kažukauskė and Kažukauskas (2015), they found that firms start to sell if their excess allowance is around the number of 5,000 allowances.

The first aim of this paper is to figure out the determinants of the propensity to trade allowances and how this propensity did response to the institutional changes from phase to phase and over time. The second aim is to quantify the opportunity costs of those firms that did not sell their allocation surplus. The approach is that these costs can be directly revealed by using the European Union Transaction Log linked with annual average transaction price data.

The paper is structured as follows: Section 2 and Appendix A give an overview of the data and the key differences between phase I, phase II and phase III. The European Union Transaction Log, where all the emissions trading compliance and transaction data is stored, is described as well as the construction of the underlying dataset. Section 3 presents a descriptive analysis of the data regarding characteristics of participants in phase I and III and their trading behavior. Section 4 begins by explaining the econometric strategy used in order to identify the drivers of the decision to trade or not to trade allowances. Then, the propensity to trade is estimated empirically using a panel probit regression model for the years 2005-2014, including phase I, II and the first two compliance years of phase III. By applying a counterfactual analysis in section 5, the opportunity costs of non-participating in trading activities are quantified. In section 6 the results are discussed and conclusions are drawn.

2 Data and Challenges regarding Institutional Differences between Phase I and Phase III in the EU ETS

Compliance and transfer data of the European Union emissions trading system (EU ETS) are stored in the European Union Transaction Log (EUTL). Data is freely downloadable in the European Union registry[4], which covers all participating countries. The EUTL includes operator holding accounts for more than 11'000 stationary installations and, since 2012, also for aircraft operators. Every operator holding account (OHA) is identified by its account identifier. It records the compliance data including the allocated allowances, the verified allowances and the surrendered allowances as well as additional information such as a registry code, referring to its country, the

[4] Website of the European Union Transaction Log: https://ec.europa.eu/clima/ets/welcome.do

account type, the account holder name, the sector affiliation via the main activity code, subsidiary and parent company names as well as opening and closing dates for every account. The second important account type are person holding accounts (PHA). These accounts can be opened for trading purposes by companies and individuals to hold and transfer units without compliance obligations. The transactions database is separately stored. It records all transactions of the European Union emissions allowances (EUA) between the different operators and person holding accounts as well as administrative transactions. One EUA refers to one ton of greenhouse gas emission. Compliance and transactions data can be linked via the account ID. The EU ETS has just ended its third phase which lasted from 2013-2020. For this third trading period the registry regulation was amended (European Union, 2013). This third phase is different from the first (2005-2007) as well as from the second (2008-2012) phase. The most important changes between the three phases, relevant for this analysis, are summarized in Table 2.1.

Table 2.1. Differences between Phase I, Phase II and Phase III of the European Union Emissions Trading System.

Topic	Phase I (2005-2007)	Phase II (2008-2012)	Phase III (2013-2020)
Participants	Power generators and energy-intensive industries above certain capacity thresholds defined Annex I of the European Union Directive 2003/87.	Aviation sector included by 1 January 2012.	Additional sectors included.
Coverage	CO2 emissions	Additional greenhouse gases included as nitrous oxide.	Additional greenhouse gases included as perfluorocarbons.
Cap	According to National allocation plans5.	The cap was reduced by 6.5% lower compared to 2005.	The cap is linearly reduced by 1.74% of the average total quantity of allowances issued annually in 2008-2012 (21% reduction in 2020 compared to 2005).
Penalty for non-compliance	Euro 40 per ton	Euro 100 per ton	Euro 100 per ton
Allocation method	Free allocation	The share of free allocation is around 90%. Allowances not allocated for free are auctioned.	The share of free allocation decreases from 80% in 2013 to 30% in 2020. Allowances not allocated for free are auctioned. Airlines are still free allocated based on an efficiency benchmark.
Banking	Banking within phase I. Banked allowances could not be carried over to phase II.	Banking within phase II. At the end of phase II banked allowances were carried over to phase III.	Banked allowances from phase II and phase III could be used for compliance.
Back-loading of auctions in phase III	-	Due to the economic crisis in phase II, a surplus of around 2.1 billion allowances accumulated at the start of phase III. The commission reduced the auction volume in 2014, 2015 and 2016 to 900 million allowances and postponed it until 2019 and 2020.	

Source: European Union Commission, Additional information available at: https://ec.europa.eu/clima/policies/ets_en

[5] The national allocation plans are published by the European Commission: https://ec.europa.eu/clima/policies/ets/pre2013/nap_en#tab-0-1

In Appendix A the construction of the panel dataset is explained in detail. The final dataset includes all compliance data from phases I to III for the compliance years 2005-2014 as well as all the relevant transferring and acquiring transactions between the participating firms.

3 Descriptive Analysis of the Trading Behavior of Phase I and Phase III

Using methods of descriptive statistics, this section summarizes the differences of the trading participation between the first two years of phase I (N = 8,486) and the first two years of phase III (N = 8,919). Between these two samples, various revisions of the EU ETS have been introduced (see Table 2.1). The aim of this section is to gain an understanding of the determinants of participation in trading and of how participation has been changing between phase I and phase III. The determinants are then used as independent explaining variables in the regression model of section 4. Table 3.1 explains the relevant definitions used in this paper.

Table 3.1. Definitions used in the EU ETS sample.

Definition	Calculation
Allocation Position of firm i in year t =	
Allocated Allowances – Verified Emissions	$a_{it} - e_{it}$
Allocation surplus: The net position of firm i in year t is "long".	$a_{it} - e_{it} > 0$
Allocation deficit: The net position of firm i in year t is "short".	$a_{it} - e_{it} < 0$
Allocation balanced: Firm i in year t is compliant.	$a_{it} - e_{it} = 0$
Annual Balance of firm i in year t =	
Allocated Allowances – Surrendered Allowances + Purchases – Sales	$ab_{it} = a_{it} - s_{it} + purch_{it} - sales_{it}$
(In case of no trade, the allocation position is equal to the annual balance.)	
Banking of firm i in phase T	$banking_i = \sum_{t=t}^{T} ab_{it}$
Banked allowances at the end of phase I expired.	
Banked allowances at the end of phase II were carried over to phase III.	

Figure 3.1 reveals that in the first two years of phase I (years 2005-2006), the majority of the firms' allocation positions, apart from large emitters, were in both compliance years long. For these firms, there was no need to engage in allowance trading activities. In phase III (years 2013-2014), however, the majority of the firms' allocation positions were at least once short. These firms needed to trade unless they had banked allowances from the previous phase II. In general, for both periods, larger emitters tend to have shorter allocation positions.

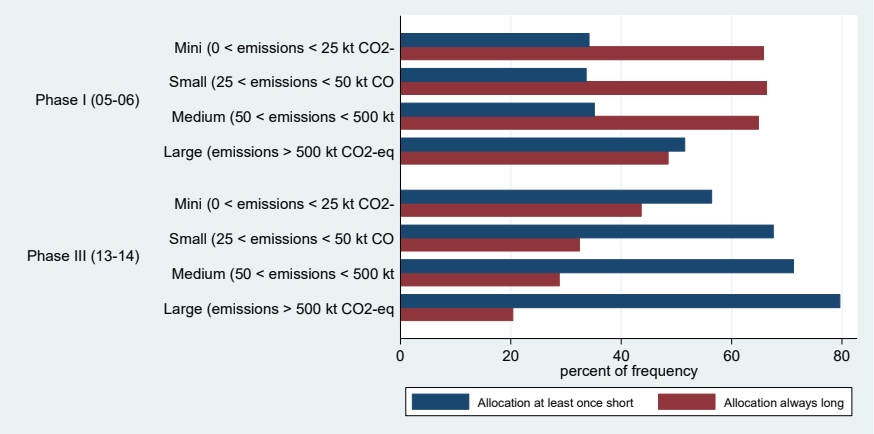


Figure 3.1. Comparison of the Distribution of the Allocation Position of the Firms in Phase I and Phase III.

Note: The sum of the relative frequency per category (e.g. Phase III / Large) is 100%.

In Figure 3.2 trading participation is included in the graphs. Allowance trading of phase I and III are compared. In addition, the relative frequencies are distinguished according to both the allocation positions ($a_{it} - e_{it}$) and the size. The term "allocation always long" refers to those firms never facing a negative allocation position in these two years. The trading participation between the two phases is mirrored. While, in the first two years of phase I, most firms prefer not to trade (blue bars), in the first two years of phase III the opposite is the case (red bars). These results fulfill the expectations. The trading behavior seems to have changed independent of the allocation position. The differences between these trading activities of short and long firms seem to be small. The reason for an increase in trading activities cannot be found exclusively in the allocation position.

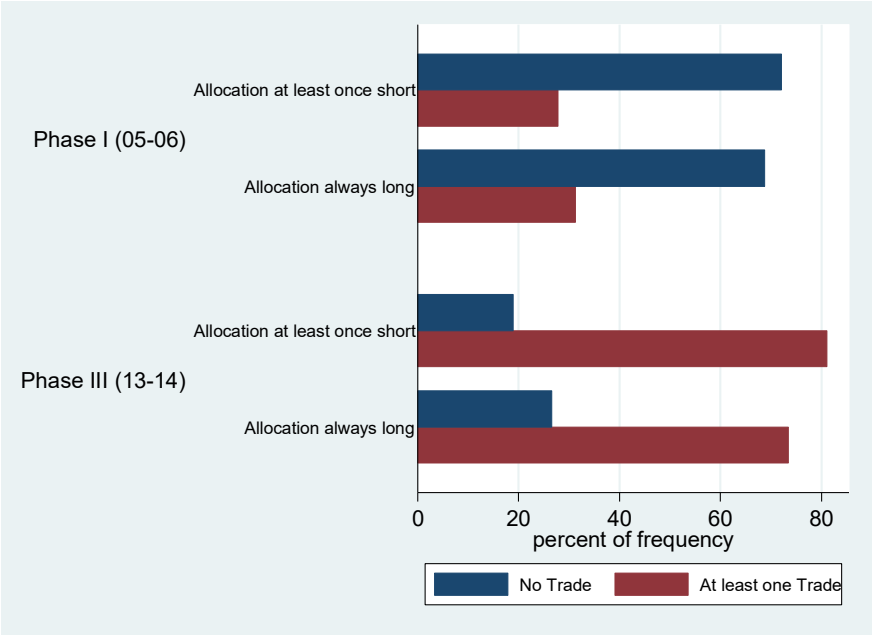
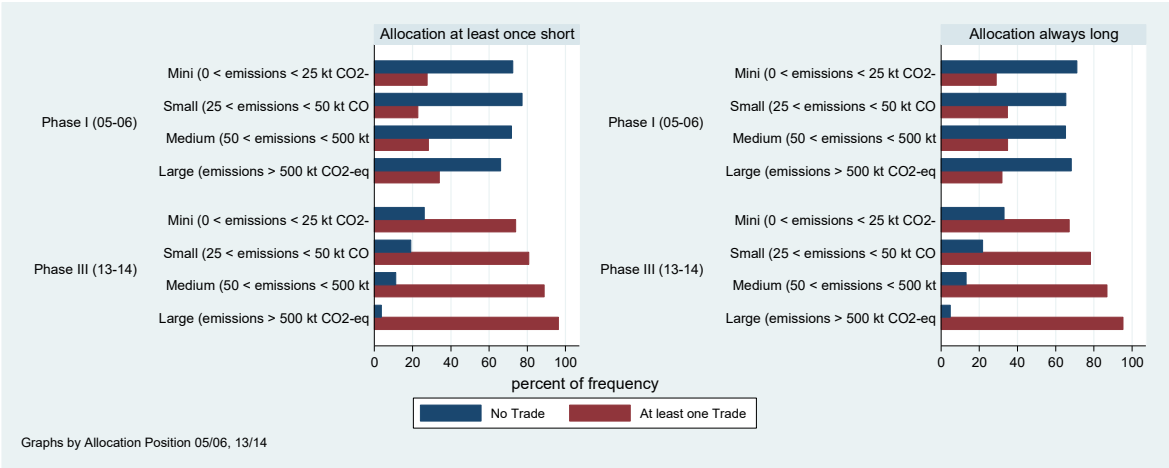
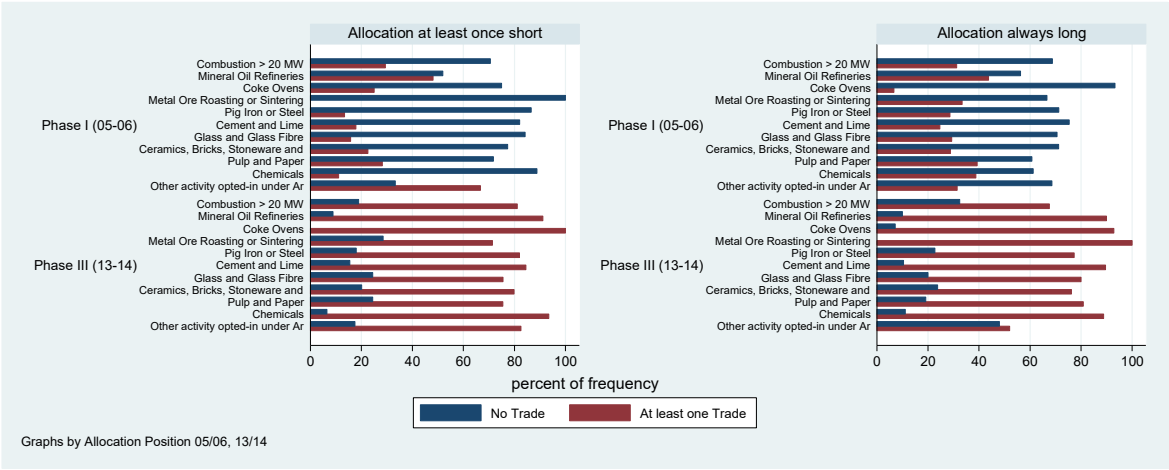


Figure 3.2. Distribution of the firms in phase I and III according to the allocation position and the trading participation.

Note: The sum of the relative frequency per category (e.g. Phase III / Allocation always long) is 100%.

Figure 3.3 shows the same comparison, but additionally grouped by size, sector and the one- year-lagged banking position. The first graph reveals that in phase I the trading participation does not depend on the size of the firms, measured in emissions. However, in phase III, besides on overall increasing trading rate, larger firms tend to conduct more trades than smaller firms independent of their allocation position. Regarding the sectors in the second graph, refineries, coke ovens, metal ore roasting, cement and chemicals seem to be slightly more active in trading activities than other sectors. The last graph reveals the relation between banking positions and trading activities.





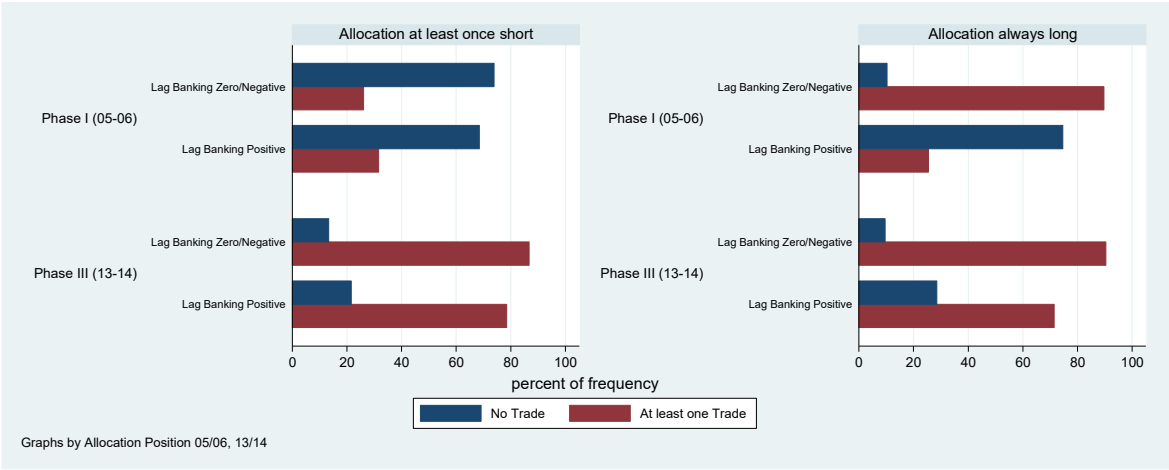


Figure 3.3. Distribution of the firms in phase I and III according to the allocation position and the trading participation, grouped by size (first graph) by sector (second graph) and by banking position (third graph).

Note: The sum of the relative frequency per category (e.g. Phase III / Large / Allocation always long) is 100%

The last graph differs between short and long allocation positions in phase I. Firms with one or more short positions in phase I or phase III (left graph) increase their trading activities from roughly 30% in phase I to

80% in phase III independent of their banking position. Firms with long positions (right graph) tend to trade more if the banking position is negative in phase I and phase III. In phase III, firms tend to trade more, especially when their banking position is negative. This indicates that banking, which is mainly the result of the cumulated allocation surplus in previous compliance years, plays, beside the allocation position, an important role in deciding whether to engage in trading activities, especially in phase III. In the next session, the econometric strategy and the results of the regression analysis are explained to test whether the insights of this sections are significant.

4 Regression Analysis of the Trading Behavior between 2005- 2014

In subsection 4.1 the econometric strategy to estimate trading behavior of the participants of the EU ETS is explained. Subsection 4.2 shows and explains the results of the binary choice model using panel data extracted from the European Union Transaction Log.

4.1 Econometric Strategy

The decision to participate in trading or not as seller, buyer or both can be described using binary choice models. The underlying latent variable model is modelled as follows:

(1) $$y^*_{it} = \boldsymbol{x'_{it}\beta} + \boldsymbol{z'_i\gamma} + \eta_i + \varepsilon_{it}$$

where y^*_{it} is the unobserved dependent variable. It is based on the observed indicator function $y_{it} = 1[y^*_{it} > 0]$ which takes on the value one if installation i conducted at least one trade in period t and zero otherwise. The binary response probability is

(2) $$P(y_{it} = 1 \mid \boldsymbol{x_{it}, z_i}, \eta_i) = \Phi(\boldsymbol{x'_{it}\beta} + \boldsymbol{z'_i\gamma} + \eta_i + \varepsilon it)$$

where $\mathbf{x_{it}}$ are the entity-specific[6] time-varying variables such as the logarithm of the yearly allocation position, η_i are entity-specific unobserved time-constant effects such as firm culture, management behavior or firm-specific technology. The $\mathbf{z_i}$ are entity specific time-invariant observed characteristics, such as sector affiliation, country and size. In a fixed effects specification these variables would drop out, in a random effects specification, however, they do not do so.

Yet, fitting non-linear binary dependent variable models with unobserved individual effects, does suffer from the incidental parameter problem. In our panels with N being larger than 8,000 observations and T between 2 and 10 years, depending on the estimation, fixed effects estimates will be biased and inconsistent (see Chamberlain, 1984). Random effects models require the restrictive assumption that the unobserved effect α_i is uncorrelated with all the explanatory variables. The correlated random effects (CRE) approach is an alternative, which controls for potential correlation between the random effect and the exogenous variables. Following Mundlak (1978) and assuming for time-varying regressors $\bar{x}_i$ as the average of the x_{it} over t = 2005, 2006, 2007 for phase I, t = 2008, 2009, 2010, 2011, 2012 for phase II, t = 2013, 2014 for phase III and finally t = 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014 the unobserved heterogeneity is modelled according to

(3) $$\eta_i = \boldsymbol{\bar{x}'_i\gamma} + \alpha_i$$

Since η_i and x_{it} are correlated whenever $\gamma \neq 0$, the α_i must be uncorrelated with x_{it} and the binary response probability model can be written as

(4) $$P(y_{it} = 1 \mid \boldsymbol{x_{it}, \bar{x}_i, z_i}, \alpha_i) = \Phi(\boldsymbol{x'_{it}\beta} + \boldsymbol{\bar{x}'_i\gamma} + \boldsymbol{z'_i\gamma} + \alpha_i + \varepsilon_{it})$$

[6] With entity I refer to an installation covered by the EU ETS.

The composite error term, $\alpha_i + \varepsilon_{it}$, consists of the time-invariant unobservable entity-specific effect α_i which controls the correlation with x_{it} and the idiosyncratic error term ε_{it}. In accordance with empirical economists I call x_i the "Mundlak term".

In a first step I estimate every phases separately (specifications 1 - 3). Additional year dummies correct for the time effect compared to the first trading year of the phase. In a second step, all phases together are estimated using additional dummies to compare phases II and III with the baseline phase I (specification 4). In a third step the propensity to trade is estimated separately for purchasing allowances (specification 5) and selling allowances (specification 6). All variable used in the regressions are summarized in Table 4.1.

Table 4.1. Description of the variables used in the binary dependent variable regression models.

Variable	Description	Measurement Unit
Dependent Variable: Trade (0 = No, 1 = Yes) Buyer (0 = No, 1 = Yes) Seller (0 = No, 1 = Yes)	The variable equals one if a trade is conducted in the respective year. In certain regressions the dependent variable is distinguished between buyer and seller trade. Only trades between firms (market trades), no intra-firm trades are considered.	Dummy variable
Log(1+Allocation Position)	Natural logarithm of one plus the absolute value of the allocation position (= allocated allowances – verified allowances) times the sign of the allocation position.	Numeric variable
Log(1+Lag Banking)	Natural logarithm of one plus the one year lagged banked allowances times the sign of lagged banking.	Numeric variable
Number of installations	Number of single installations belonging to the same firm.	Numeric variable
Subsidiary	The variable is one if the firm belongs to a parent firm.	Dummy variable
Size Category = 1	Mini (0 < emissions < 25 kt CO_2-eq).	Categorical variable
Size Category = 2	Small (25 < emissions < 50 kt CO_2-eq).	Categorical variable
Size Category = 3	Medium (50 < emissions < 500 kt CO_2-eq).	Categorical variable
Size Category = 4	Large (emissions > 500 kt CO_2-eq).	Categorical variable
Sectors	Sector affiliation and share as a percentage of all firms described in Appendix C.	Categorical variable
Year	Dummy for trading year (Baseline years: 2005 for phase I, 2008 for phase II, 2013 for phase III).	Dummy variable
Period	Dummy variable for period (Baseline is period 05-07 for phase II and period 08-12 for phase III).	Dummy variable
Mundlak Term	Average of time-varying covariates x_{it} over entity i of the relevant period to use random effects models.	Numeric variable

In Table 4.2 the data used for the following regression analysis for the trading years 2005-2014 is summarized. The size categories are already described in Figure 1.1. Detailed information on the sectors can be found in Appendix C. Data is described in absolute values in order to be interpreted more easily.

Table 4.2. Summary statistics of the variables used in the panel probit regression specifications.

Phase	Year	Variable	Percent	N	Mean	Median	Std.Dev.
2005-2007	2005	Allowance Allocation	-	8,486	219,352	21,306	1,007,375
		Verified Emissions	-	8,486	208,278	16,512	1,013,194
		Allowances Surrendered	-	8,486	175,337	9,009	970,785
		Allocation Position	-	8,486	11,074	2,127	227,213
		Allowances Purchase	-	8,486	11,508	0	187,191
		Allowances Sale	-	8,486	18,832	0	233,068
		Annual Balance	-	8,486	36,691	2,091	398,045
		Banking	-	8,486	36,691	2,091	398,045
		Percentage of Traders	19.01	8,486	-	-	-
		Percentage of Buyers	7.67	8,486	-	-	-
		Percentage of Sellers	15.21	8,486	-	-	-
	2006	Allowance Allocation	-	8,486	217,550	21,765	1,003,943
		Verified Emissions	-	8,486	209,441	16,048	1,006,947
		Allowances Surrendered	-	8,486	241,835	18,522	1,137,164
		Allocation Position	-	8,486	8,108	2,469	238,954
		Allowances Purchase	-	8,486	11,834	0	174,447
		Allowances Sale	-	8,486	20,326	0	209,490
		Annual Balance	-	8,486	-32,778	296	401,214
		Banking	-	8,486	3,913	2,218	448,013
		Percentage of Traders	23.23	8,486	-	-	-
		Percentage of Buyers	10.29	8,486	-	-	-
		Percentage of Sellers	17.1	8,486	-	-	-
	2007	Allowance Allocation	-	8,486	219,686	22,490	1,007,383
		Verified Emissions	-	8,486	212,291	15,685	1,018,303
		Allowances Surrendered	-	8,486	213,563	15,664	1,034,260
		Allocation Position	-	8,486	7,396	3,139	242,929
		Allowances Purchase	-	8,486	17,590	0	177,440
		Allowances Sale	-	8,486	16,689	0	187,552
		Annual Balance	-	8,486	7,024	2,168	245,422
		Banking	-	8,486	10,937	3,545	560,984
		Percentage of Traders	31.3	8,486	-	-	-
		Percentage of Buyers	18.35	8,486	-	-	-
		Percentage of Sellers	18.07	8,486	-	-	-
2008-2012	2008	Allowance Allocation	-	9,245	184,771	19,946	791,270
		Verified Emissions	-	9,245	197,723	15,580	940,483
		Allowances Surrendered	-	9,245	196,093	15,353	940,708
		Allocation Position	-	9,245	-12,952	1,565	374,949
		Allowances Purchase	-	9,245	18,200	0	235,983
		Allowances Sale	-	9,245	28,979	0	262,531
		Annual Balance	-	9,245	-22,102	295	427,363
		Banking	-	9,245	-22,102	295	427,363
		Percentage of Traders	30.45	9,245	-	-	-
		Percentage of Buyers	17.79	9,245	-	-	-
		Percentage of Sellers	25.33	9,245	-	-	-
	2009	Allowance Allocation	-	9,245	186,633	20,778	792,438
		Verified Emissions	-	9,245	176,163	13,849	866,626
		Allowances Surrendered	-	9,245	179,391	13,832	890,595
		Allocation Position	-	9,245	10,469	3,497	380,334
		Allowances Purchase	-	9,245	12,740	0	110,881
		Allowances Sale	-	9,245	22,501	0	176,406
		Annual Balance	-	9,245	-2,520	1,388	403,884
		Banking	-	9,245	-24,622	1,123	724,849
		Percentage of Traders	30.34	9,245	-	-	-
		Percentage of Buyers	17.06	9,245	-	-	-
		Percentage of Sellers	23.33	9,245	-	-	-
	2010	Allowance Allocation	-	9,245	189,919	21,306	796,652
		Verified Emissions	-	9,245	181,995	14,525	891,339
		Allowances Surrendered	-	9,245	181,285	14,350	891,686
		Allocation Position	-	9,245	7,924	2,812	377,287
		Allowances Purchase	-	9,245	24,184	0	300,113
		Allowances Sale	-	9,245	35,781	0	356,907
		Annual Balance	-	9,245	-2,963	1,206	407,093
		Banking	-	9,245	-27,585	2,022	1,059,055
		Percentage of Traders	32.16	9,245	-	-	-
		Percentage of Buyers	21.55	9,245	-	-	-
		Percentage of Sellers	23.46	9,245	-	-	-
	2011	Allowance Allocation	-	9,245	192,265	21,405	802,558
		Verified Emissions	-	9,245	178,492	13,336	919,457
		Allowances Surrendered	-	9,245	177,252	13,132	917,749
		Allocation Position	-	9,245	13,773	3,924	393,251
		Allowances Purchase	-	9,245	32,942	0	282,895
		Allowances Sale	-	9,245	47,005	0	565,549
		Annual Balance	-	9,245	950	2,733	523,472
		Banking	-	9,245	-26,635	4,401	1,430,912
		Percentage of Traders	33.36	9,245	-	-	-
		Percentage of Buyers	25.34	9,245	-	-	-
		Percentage of Sellers	23.13	9,245	-	-	-
	2012	Allowance Allocation	-	9,245	196,570	21,490	843,886
		Verified Emissions	-	9,245	175,285	12,527	972,123
		Allowances Surrendered	-	9,245	175,584	12,442	973,676
		Allocation Position	-	9,245	21,285	4,526	422,859
		Allowances Purchase	-	9,245	130,998	3,810	716,524
		Allowances Sale	-	9,245	81,536	0	547,990
		Annual Balance	-	9,245	70,448	5,831	480,818
		Banking	-	9,245	43,813	10,000	1,518,401
		Percentage of Traders	73.79	9,245	-	-	-
		Percentage of Buyers	65.73	9,245	-	-	-
		Percentage of Sellers	45.54	9,245	-	-	-
2013-2020	2013	Allowance Allocation	-	8,919	100,821	16,921	485,165
		Verified Emissions	-	8,919	152,711	16,547	921,829
		Allowances Surrendered	-	8,919	153,232	16,511	933,395
		Allocation Position	-	8,919	-51,890	-311	758,772
		Allowances Purchase	-	8,919	75,144	0	569,578
		Allowances Sale	-	8,919	40,238	0	411,173
		Annual Balance	-	8,919	-17,506	53	526,921
		Banking	-	8,919	25,194	8,880	1,712,987
		Percentage of Traders	54.31	8,919	-	-	-
		Percentage of Buyers	46.23	8,919	-	-	-
		Percentage of Sellers	26.07	8,919	-	-	-
	2014	Allowance Allocation	-	8,919	94,163	15,458	462,929
		Verified Emissions	-	8,919	146,988	14,717	891,819
		Allowances Surrendered	-	8,919	147,329	14,718	892,248
		Allocation Position	-	8,919	-52,826	-121	736,098
		Allowances Purchase	-	8,919	73,360	276	590,991
		Allowances Sale	-	8,919	53,200	0	546,156
		Annual Balance	-	8,919	-33,005	0	676,594
		Banking	-	8,919	-7,812	7,651	2,116,163
		Percentage of Traders	64	8,919	-	-	-
		Percentage of Buyers	53.3	8,919	-	-	-
		Percentage of Sellers	33.97	8,919	-	-	-

The first four variables are the compliance data originating from the EUTL. Note that in 2013 there is a sharp drop in in the allowance allocation. This results from the introduction of actioning allowances instead of distributing them freely (see Table 4.1). Auctioned allowances must be purchased in the primary or secondary market. Since firms anticipated the auctions, the number of purchased allowances is therefore increasing already in the year 2012. The resulting allocation positions ($a_{it} - e_{it}$) start to be negative from the beginning of phase III. Average verified emissions are 208,278 tons of CO_{2eq} in year 2005. They drop to 146,988 tons of CO_{2eq} in year 2014, which follows from the reduction of the overall cap (see also second graph of Figure 1.2). The amount of allowance purchase and sales is increasing every year with the above-mentioned peak in 2012. Until 2011 all median values of the purchased and sold allowances are zero since most firms in these years did not participate in trading activities. This can also be seen in the variable "percentage of traders" which exceeded 50% for the first time in 2012. Another consequence of auctioning allowances is the that the percentage of buyers exceeds the percentage of sellers from beginning in 2012. In the next subsection, the results of these estimations are presented.

4.2 Regression Results of the Comparison of Phase I, Phase II and Phase III

In this section, all trading and compliance data from 2005 to 2014 (10 years) is used to estimate the panel data probit model explained theoretically in subsection 4.1. Table 4.3 shows the regression results[7]. The variables discussed are all significant on the 1 or 5 percent level.

To avoid right skewed distributions of the independent variables, the allocation position and the one-year-lagged banking position are transformed into logarithms. The logarithm of the allocation position has a negative sign, except in phase II (specification 2). Larger allocation positions reduce the propensity to engage in trading activities. This result was expected. The reason for the positive sign in phase II might be that at the beginning of phase II, no firm had banked allowances since allowances from phase I expired at the end of the compliance cycle in phase I. Phase II was also special regarding other issues. Many countries suffered from a financial crisis and their economy was running below the maximal capacity. As a result, allocated allowances exceeded verified allowances in every year except in 2008, when the crisis had not yet hit (see Table 4.2). The pressure to buy allowances was low. Some firms might even have taken advantage of their positive allocation positions and sold a part of their excess allocation. Specification 6 would support this assumption since the relation between the allocation position and the propensity to act as a seller is positive as well. Another issue of phase II was the VAT carousel that rocked the second phase (see e.g. Frunza, 2013). Therefore, estimation results of phase II should be treated with caution. The same reasoning applies to the logarithm of the one-year-lagged banking position. Larger banking positions reduce the pressure to engage in trading. When the binary depending variable is the decision to engage in trading as a buyer (specification 5) or as a seller (specification 6), the coefficients have the expected sign. Larger allocation as well as banking positions reduce the propensity to buy allowances and increase the propensity to sell allowances.

The number of installations belonging to the same firms is positively linked to a trading decision. In all the six estimated specifications, the number of installations has a positive impact on the decision to engage in trading. This could be an indication of the benefits of economies of scale in emissions trading. Firms belonging to a parent company (variable: subsidiary company) tend to engage more in trading than stand-alone firms do. The coefficients are positive but only significant in specification 4, which covers all phases and in specification 6, when firms act as sellers.

[7] Prices are not included in the regression because of collinearity with the variable year. On a yearly basis with average yearly allowance prices, prices and years would be perfectly collinear.

Table 4.3. Panel probit estimation results for phase I, phase II and phase III and for all phases.

Dependent Variable: Trade (0 = No, 1 = Yes) VARIABLES	(1) Probit 2005-2007	(2) Probit 2008-2012	(3) Probit 2013-2014	(4) Probit 2005-2014	(5) Probit Buyer 2005-2014	(6) Probit Seller 2005-2014
Log(1 + Allocation Position)	-0.0204**	0.00850**	-0.00848**	-0.00458**	-0.0206**	0.0255**
	(0.00237)	(0.00165)	(0.00182)	(0.000887)	(0.000897)	(0.00101)
Log(1 + Lag Banking)	-0.00578**	0.00802**	-0.0176**	0.00307**	-0.00991**	0.0248**
	(0.00210)	(0.00149)	(0.00223)	(0.000867)	(0.000898)	(0.000970)
No. of Installations	0.0245**	0.140**	0.121+	0.0246**	0.0358**	0.0244**
	(0.00930)	(0.0339)	(0.0629)	(0.00922)	(0.0121)	(0.00897)
Is Subsidiary Company = 1, Is Subsidiary	0.0339	0.0405	0.0439	0.0533*	0.0130	0.0846**
	(0.0662)	(0.0381)	(0.0381)	(0.0233)	(0.0228)	(0.0239)
Size Category = 2, Small (25 < emissions < 50 kt CO2-eq)	0.305**	0.354**	0.258**	0.269**	0.255**	0.216**
	(0.0483)	(0.0308)	(0.0332)	(0.0192)	(0.0183)	(0.0203)
Size Category = 3, Medium (50 < emissions < 500 kt CO2-eq)	0.414**	0.561**	0.557**	0.439**	0.455**	0.396**
	(0.0445)	(0.0294)	(0.0329)	(0.0183)	(0.0175)	(0.0194)
Size Category = 4, Large (emissions > 500 kt CO2-eq)	0.638**	0.773**	1.128**	0.598**	0.606**	0.619**
	(0.0709)	(0.0463)	(0.0621)	(0.0303)	(0.0279)	(0.0304)
Sector = 2, Mineral Oil Refineries	0.749**	0.364**	0.0662	0.302**	0.163*	0.206**
	(0.163)	(0.118)	(0.121)	(0.0786)	(0.0709)	(0.0695)
Sector = 3, Coke Ovens	0.0351	0.235	0.151	0.101	-0.0451	0.0725
	(0.221)	(0.176)	(0.284)	(0.105)	(0.107)	(0.119)
Sector = 4, Metal Ore Roasting or Sintering	-0.448	-0.264	-0.325	-0.261+	-0.161	-0.190
	(0.434)	(0.230)	(0.365)	(0.142)	(0.133)	(0.188)
Sector = 5, Pig Iron or Steel	-0.283**	-0.237**	-0.0764	-0.0136	0.0608+	-0.183**
	(0.109)	(0.0650)	(0.0524)	(0.0371)	(0.0339)	(0.0401)
Sector = 6, Cement and Lime	-0.353**	0.194**	-0.172**	0.0301	0.0454	0.00636
	(0.0863)	(0.0533)	(0.0633)	(0.0318)	(0.0303)	(0.0330)
Sector = 7, Glass and Glass Fibre	0.0378	0.00351	-0.405**	-0.0870**	-0.154**	0.0551
	(0.0859)	(0.0520)	(0.0572)	(0.0332)	(0.0308)	(0.0344)
Sector = 8, Ceramics, Bricks, Stoneware and Porcelain	0.0855	0.365**	-0.0161	0.200**	0.185**	0.195**
	(0.0521)	(0.0345)	(0.0387)	(0.0210)	(0.0208)	(0.0222)
Sector = 9, Pulp and Paper	0.120+	0.0290	0.0653	0.0569*	-0.0156	0.101**
	(0.0625)	(0.0442)	(0.0515)	(0.0286)	(0.0272)	(0.0279)
Sector = 10, Chemicals	-0.263	0.133	0.419**	0.352**	0.192**	0.343**
	(0.185)	(0.108)	(0.0709)	(0.0521)	(0.0458)	(0.0505)
Sector = 99, Other activity opted-in under Art. 24	-0.408**	-0.258**	-0.537**	-0.321**	-0.248**	-0.248**
	(0.117)	(0.0896)	(0.106)	(0.0588)	(0.0562)	(0.0613)
Year = 2006 (BL 2005)	0.274**					
	(0.0282)					
Year = 2007 (BL 2005)	0.701**					
	(0.0303)					
Year = 2009 (BL 2008)		-0.0234				
		(0.0192)				
Year = 2010 (BL 2008)		0.0569**				
		(0.0207)				
Year = 2011 (BL 2008)		0.101**				
		(0.0223)				
Year = 2012 (BL 2008)		1.548**				
		(0.0311)				
Year = 2014 (BL 2013)			0.337**			
			(0.0209)			
Period = 2, P08-12 (BL P05-07)				0.579**	0.747**	0.573**
				(0.0130)	(0.0150)	(0.0151)
Period = 3, P13-14 (BL P05-07)				1.134**	1.287**	0.758**
				(0.0193)	(0.0187)	(0.0209)
Mundlak Term Allocation Position	0.0422**	0.0460**	-0.00850**	0.0231**	-0.00962**	0.0599**
	(0.00466)	(0.00343)	(0.00330)	(0.00196)	(0.00190)	(0.00210)
Mundlak Term Banking	-0.0765**	-0.0992**	-0.00724+	-0.0599**	-0.0127**	-0.0924**
	(0.00467)	(0.00364)	(0.00410)	(0.00218)	(0.00213)	(0.00216)
Constant	-3.006**	-1.856**	-0.0809	-1.563**	-1.789**	-2.159**
	(0.171)	(0.0762)	(0.106)	(0.0427)	(0.0437)	(0.0497)
Observations	25,458	46,225	17,838	89,521	89,521	89,511
Number of firms in sample	8,486	9,245	8,919	12,245	12,245	12,240
Country Controls	YES	YES	YES	YES	YES	YES
Rho	0.429	0.337	0.205	0.191	0.156	0.181

Note: Asterisks and plus indicate the significance level at 1% (**), 5% (*) and 10% (+). The standard errors in parentheses are robust corrected for serial correlation across clusters. Rho is the correlation between the α_i and the idiosyncratic error term ε_{it}. The table shows the coefficients of Phase I, II, III the 2 periods panel probit estimations (Rows 1 -3) separately and the estimations for all phases (Rows 4 -6). Dependent variable: Columns 1 to 4: Trade (0 = No, 1 = Yes), Column 5: Purchase (0 = No, 1 = Yes). Column: Sale (0 = No, 1 = Yes). The binary predictor subsidiary means that the installation is part of a firm with two or more installations. The Mundlak term is the coefficient of the average logarithm of the banking with lag 1. Baseline size category 1 is "Mini (0 < emissions < 25 kt CO2-eq)". Baseline sector 1 is "Combustion > 20 MW". The year and period dummies are the coefficients against the baseline (BL) year/period. Data Source: European Union Transaction Log.

The categorical variable size is measured as average annual emissions of a firm. The baseline category are the mini installations (0 < emissions < 25 kt $CO_{2\text{-eq}}$). Again, not surprisingly, size does matter. The coefficient of the size is positive in all specifications. In specification 4, the coefficient for small firms is 0.269, for medium firms 0.439 and for large firms 0.598, always compared to the baseline size category "mini". By having a closer look at the coefficients of the different sectors, it is apparent that sectors with large installations such as refineries or cement show significantly positive or negative coefficients compared to the baseline sector combustion of fuels, which covers 62.5 percent of the installations. To make phase III sectors comparable with phase I sectors, the sectors needed to be translated into a unique category system at the cost of losing some information - as explained in section 1 [8]. The sector affiliation in this study was introduced as an additional control variable so that to reduce statistical noise. Additional firms-specific data would open the door for new research, analyzing the differences in trading behavior of the sectors.

The compliance years can reveal a general time trend. The year dummies in specifications 1, 2 and 3, apart from 2009, which is, however not significant, are all positive and increasing. This can be due to different causes: The first cause could be that firms become experienced in trading. Another reason might be the overall allocation cap which was reduced every year by 1.74% in phase III. Thirdly, auctioning instead of free allocation tends to become the default. However, allowance trading is also open for traders such as banks or brokers who do not have to comply.

Specification (4) integrates all three trading phases. Instead of year dummies, a phase dummy shows the impact on trading compared to the baseline phase I. The probit coefficient for phase II (period 2) is 0.579 whereas for phase III (period 3) the coefficient is 1.134. This is a strong indicator that, compared to phase I, trading is significantly higher. The effect of the changes from phase to phase (see Table 2.1) is manifested in an increasing participation in trading activities.

To illustrate the evolution of these trading activities Figure 4.1 shows the cumulated share of those firms that never conducted a trade - grouped by size (left graph) and sector (right graph). At the beginning of phase III (2013), the share of those firms that never conducted a trade is around 10% or less. The sharp decrease in 2012 is due to the implementation of the auctioning scheme instead of free allocation which is explained in Table 2.1. Regarding the size, the first graph reveals that the decrease of the share of never-traders drops faster in the group of large firms. The sector graphs indicate that large emitters, such es mineral oil refineries, coke ovens or cement tend to engage faster in trading activities than the others. However, as already mentioned, sector analysis was not the main aim of this paper.

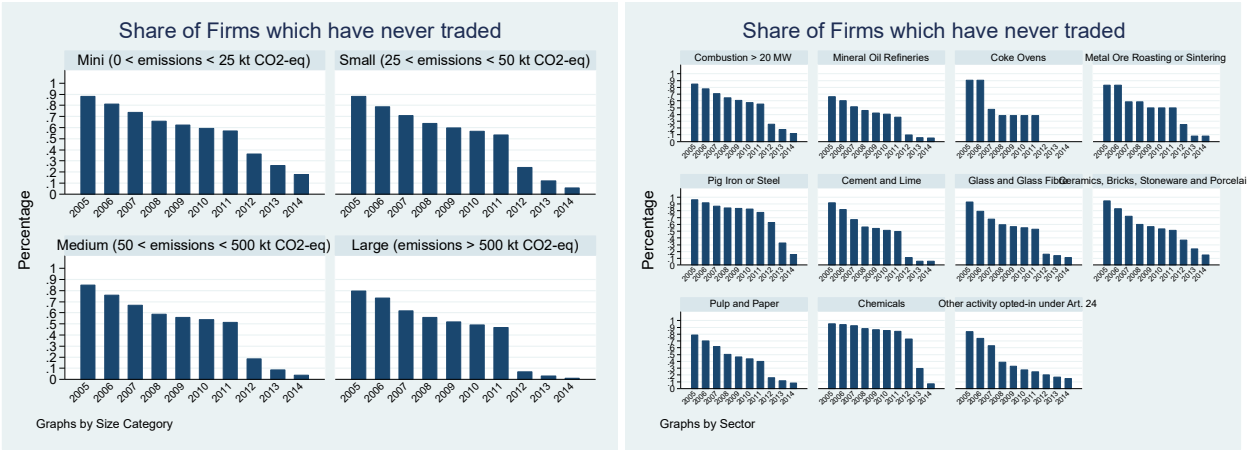


Figure 4.1. Share of firms which have never traded.

[8] The translation scheme can be found in Appendix C.

5 An Alternative Approach to Estimate the Opportunity Costs of the Non-trading Decision of Entities

After having analyzed trading behavior in general, my focus in this section is on those firms which, despite a positive allowance allocation, did not participate in trading. These companies did not use the opportunity to sell their allocation surplus and, therefore, forewent revenues. These forgone revenues are the opportunity costs of non-participating in trading activities. High opportunity costs indicate high trading barriers such as information, search or broker fee costs.

The objective of this section is to quantify these opportunity costs by matching the non-trading firms with trading firms. To be comparable, the two groups must have as many characteristics in common as possible. To show the evolution of the emissions market, Phase I (2005-2007) is compared with Phase II phase III up to the two first trading years (2008-2014). The process of revealing these opportunity costs is conducted step by step and is summarized in Table 5.1. The results of every step will then be explained in detail.

Table 5.1. Steps to estimate the causal effect of the non-trading decision of firms with long allocations positions by matching treatment and control group by propensity score matching.

Step	Description
1	Extract firms with positive net allocation throughout the whole phase I respectively phase II / III
2	Split the firms from step 1 into two groups: Treatment group: Non-traders in the relevant period Control group: Traders with at least one allowance sale and no purchase in the relevant period
3	Define the outcome variable per firm i: phase I: $pua_i = \sum_{t=2005}^{2007} \frac{ab_{it}}{a_{it}}$; phase II & III: $pua_i = \sum_{t=2008}^{2014} \frac{ab_{it}}{a_{it}}$; where pua_i = Unsold allowances as a percentage of the total allocated allowances. This is the sum of the annual balance ($\sum ab_{it}$) divided by the sum of the allocated allowances ($\sum a_{it}$) in the relevant period.
4	By the technique of propensity score matching, assign to every treatment unit its counterfactual unit from the control group with similar characteristics. A binary dependent variable logistic regression model with baseline control variables extracted from the EUTL is applied. The control variables are the logarithm of the size, the logarithm of the allocation – emissions summed up over the relevant period and the categorical variables, sector affiliation and country. $P(y_i = 1 \mid x_i) = \Phi(x'_i\beta + \varepsilon_i)$; where $y_i = 1$ if firm i belongs to the treatment group and $y_i = 0$ if firm i belongs to the control group
5	Calculate the causal effect of the non-trading decision for the treated firms i. The causal effect of non-trading allowances is the difference of the outcome variable of firm i minus the outcome of its counterfactual firm i': $\Delta pua_i = pua_i - pua_{i'}$
6	Calculate the hypothetical foregone earnings for the treated firms i over the relevant period (hypfe): phase I: $hypfe_i = \Delta pua_i \cdot \sum_{t=2005}^{2007} allocation_{it} \cdot price_t$; phase II & III: $hypfe_i = \Delta pua_i \cdot \sum_{t=2008}^{2014} allocation_{it} \cdot price_t$

Step	Description
7	Calculate the absolute and relative opportunity cost of non-participating in trading activities over the relevant period:
7a	Opportunity costs per year of all firms belonging to the treatment group: $\text{phase I: OC/year} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{3}$; $\text{phase II \& III: OC/year} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{7}$
7b	Opportunity costs per non-sold allowance of all firms belonging to the treatment group: $\text{phase I: OC/allowance} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{\sum_{i=1}^{n} \sum_{t=2005}^{2007} \text{ab}_{it}}$; $\text{phase II \& III: OC//allowance} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{\sum_{i=1}^{n} \sum_{t=2008}^{2014} \text{ab}_{it}}$
7c	Opportunity costs of non-sold allowance of all firms belonging to the treatment group as a percentage of the value of the total allocation (poc): $\text{phase I: poc} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{\sum_{i=1}^{n} \sum_{t=2005}^{2007} \text{allocation}_{it} \cdot \text{price}_t} \cdot 100$; $\text{phase II \& III: poc} = \frac{\sum_{i=1}^{n} \text{hypfe}_i}{\sum_{i=1}^{n} \sum_{t=2008}^{2014} \text{allocation}_{it} \cdot \text{price}_t} \cdot 100$

Steps 1 and 2, extracting eligible units in order to form a treatment as well as a comparison group are summarized in Table 5.2. Starting with the number of firms participating in the full EU ETS sample of the relevant phase, firms showing at least once a negative allocation position are subtracted. From this balance, all firms are subtracted that participated in trading activities. The result are firms with "long" positions in all trading years of the relevant period (phase I / phase II and III). They form the treatment group. The control group are the firms with "long" positions in all trading years of the relevant period yet made at least one sale and no purchase of allowances.

Table 5.2. Construction of the treatment and comparison group for firms in phase I (left table) and firms in phase II / III (right table).

		Number of Firms (p I)		Number of Firms (pII / III)	
	Total in Phase I		8,486		8,919
-	Allocation position at least once short	- 3,448	5,038	- 6,438	2,481
-	Trades ≥ 1	- 1,977	3,061	- 2,102	379
=	Treatment Group		3,061		379
	Total in Phase I		8,486		8,919
-	Allocation position at least once short	- 3,448	5,038	- 6,438	2,481
-	Trades = 0	- 3,061	1,977	- 379	2,102
-	Purchases ≥ 1	- 648	1,329	- 1,848	254
=	Comparison Group		1,329		254

In phase I, there were 5,038 firms that faced a long allocation in all three trading years. This number decreased to 2,481 in phase II / III. This is consistent with the gradual decrease of the distribution of the allocations. After subtracting the traders, the number of eligible units in the treatment group is 3,061 in phase I

and only 379 in phase II / III. Non-trading allowances is the exception in phase II/III. The eligible units in the control group, after subtracting the non-traders and the purchasers in phase I, consists of 1,329 firms whereas in phase II / III, the control group consists of only 254 firms.

Having prepared treatment and control group as well as the outcome variable according to steps 1 - 3, the propensity scores are calculated by applying a binary dependent variable logistic regression model given in equation (5). The dependent variable is the treatment dummy (0 = comparison group or traders, 1 = treatment group or non-traders). Every unit of the treatment group is matched to its nearest neighbor from the control group.

(5) $$P(y_i = 1 \mid \boldsymbol{x}_i) = \Phi(\boldsymbol{x}'_i\boldsymbol{\beta} + \varepsilon_i)$$

All baseline observed characteristics available in the European Union Transaction Log are included as covariates for the treatment participation probability. The control variables are explained in Table 5.1 step 4. To assess the quality of the propensity score matching for continuous covariates, the t-tests before and after matching, the standardized percentage bias[9] suggested by Rosenbaum and Rubin (1985) before and after the matching as well as the achieved percentage reduction in the absolute bias are shown. Furthermore, the variance ratio of the treated over non-treated observations are calculated. The logistic regression model and the corresponding test statistics are given in Appendix D.

To illustrate the quality of the propensity score matching, the Kernel density of the propensity scores of the treatment as well as the comparison are plotted and compared before and after the matching (Figure 5.1).

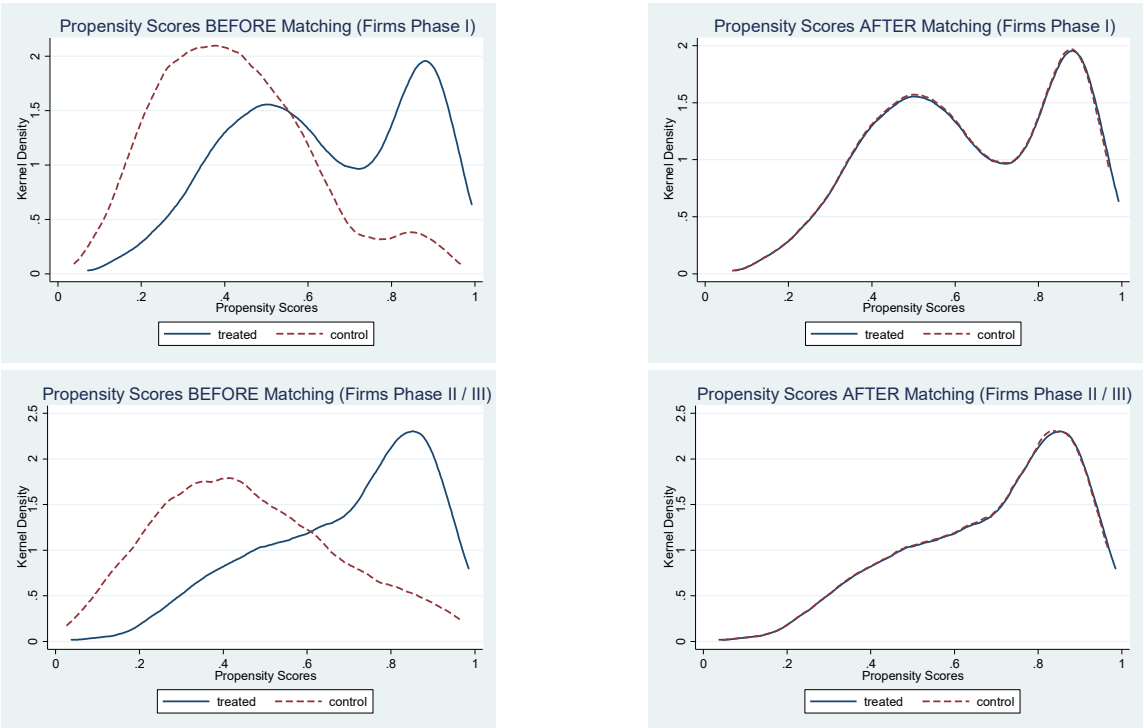


Figure 5.1. Kernel density of propensity scores between treatment and comparison group before (left graph) and after (right graph) the matching process (upper graphs: phase I, lower graphs: phase II / III).

[9] $$SB{\cdot}= 100 \cdot \frac{(\bar{X}_T - \bar{X}_C)}{\sqrt{½ \cdot (\mathrm{Var}(X_T) + \mathrm{Var}(X_C))}}$$

Based on the common support restriction, 16 observations of the treatment group in the phase I sample and 3 observations in the phase II / III sample are dropped. A total of 1'532 observations in the treatment group remain. For the phase II / III sample 359 treated units remain (see Appendix D).

In steps 5 and 6 the causal effect is calculated as the difference between the percentage of the unsold allowances for every treated unit minus the percentage of the unsold allowances of its matched counterfactual unit. Multiplying this difference with the total allowance allocation of a firm, the foregone earnings of every firm in the treatment group can be calculated. Aggregating these individual earnings over all the firms of the treatment group adds up to the total earnings which all the firms forego, due to non-participating in trading. The results of step 7 are summarized in Table 5.3 and Table 5.4.

Table 5.3. Opportunity costs and expired allowances of non-trading firms with long positions in phase I.

Size Category	Opportunity Cost (Euros)	Opportunity Cost/Year (Euros)	Banked allowances (Units)	Opportunity Cost/Allowance (Euros)
Mini (0 < emissions < 25kt CO_2-eq)	87,340,891	29,113,630	12,182,759	7.17
Small (25 < emissions < 50kt CO_2-eq)	40,041,815	13,347,272	6,947,915	5.76
Medium (50 < emissions < 500kt CO_2-eq)	183,355,395	61,118,465	39,021,349	4.70
Large (emissions > 500kt CO_2-eq)	194,521,307	64,840,436	65,658,542	2.96
Total	505,259,408	168,419,803	123,810,565	4.08
Opportunity Costs as a Percentage of the market value of the total allocated allowances (poc)	0.3437%			

Table 5.4. Opportunity costs and banked allowances of non-trading firms with long positions in phase II/III.

Size Category	Opportunity Cost (Euros)	Opportunity Cost/Year (Euros)	Banked allowances (Units)	Opportunity Cost/Allowance (Euros)
Mini (0 < emissions < 25kt CO_2-eq)	21,925,902	3,132,272	5,425,068	4.04 (7.17)
Small (25 < emissions < 50kt CO_2-eq)	6,850,302	978,615	1,554,867	4.41 (5.76)
Medium (50 < emissions < 500kt CO_2-eq)	15,727,748	2,246,821	2,017,132	7.80 (4.70)
Large (emissions > 500kt CO_2-eq)	-		-	- (2.96)
Total	44,503,951	6,357,707	8,997,067	4.95 (4.08)
Opportunity Costs as a Percentage of the market value of the total allocated allowances (poc)	0.0076%			

Table 5.3 reveals the opportunity costs of the three years of the first phase. Foregone earnings due to non-selling excess allowances sum up to 505 million Euros in phase I, which corresponds to about 168 million Euros per year. At a first glance, this number seems rather high. However, it is important to note that about one third of the companies in phase I had long positions in every trading year and still did not sell their surplus (see Table 5.2) whatever the reasons may be. Had this firms tried to sell their surplus allowances, prices would have dropped, and opportunity costs of non-trading would have decreased as well. Smaller entities face higher opportunity costs per allowance. The opportunity costs in phase I range from 7.17 Euros (mini emitters) to 2.96 (large emitters). The average opportunity costs are 4.08 Euros per allowances. The total opportunity costs as a percentage of the market value of the total allocated allowances in the year of the distribution are 0.34%. Since banking allowances to phase II was not possible, not selling allowances was not the best strategy. This indicates that in phase I, non-trading firms focused on the compliance process and not on taking advantage of trading activities. These firms precepted the opportunity costs of trading to be prohibitively high.

Table 5.4 reveals these opportunity costs for the years 2008 to 2014 of the second and the third phase. Foregone earnings due to non-selling excess allowances sum up to only 46 million Euros in phase II / III which corresponds to about 6.4 million Euros per year. Non-participating firms with permanent allocation surplus in phase II & III are a minority of about 5% (see Table 5.2). Non-trading has become the exception. Smaller entities face higher opportunity costs per allowance. The average opportunity costs have increased slightly to 4.95 Euros per allowances. However, large emitters are not present any more in this table since they face more often short positions or do participate in trading activities. Consequently, the opportunity costs - as a percentage of the market value of the total allocated allowances in the year of the distribution - are decreased to a negligible percentage of 0.0076%. Not used allowances do not expire. They can be banked and either later used for compliance purposes or sold at higher prices. The small number of non-trading entities indicates that allowance trading has by now been widely established, especially since auctioning was introduced. For the majority of the participants, opportunity costs of trading seem to have a decreasing trend. As suggested by Montgomery (1972) the European Union Emissions Trading System has clearly become more efficient.

6 Discussion and Outlook

Foregone earnings are the opportunity costs of non-participating in trading activities. The non-trading firms could perceive these trading costs as prohibitively high. The approach of this paper is to reveal the opportunity costs of those firms that do not sell their allocation surplus by directly using the European Union Transaction Log linked with annual average transaction price data. Whereas previous literature focused on surveys asking firms about their trading experience, this approach is a novel one. A comparison of these opportunity costs between phase I and phases II/III is made to capture the dynamics of 10 years of trading experience. The analysis shows that trading costs, measured as foregone earnings of not selling excess allowances, are decreasing in the number of non-trading firms and in the amount of foregone earnings between phase I and phases II/III. In section 5, for phase I and phases II/III, the causal effect on foregone earnings for those participants not selling their allowance surplus could be quantified. The opportunity costs per allowance of the units in the treatment group in phase I are 4.08 Euro and in phase II/III 4.95 Euros. These 4.95 Euros, however, refer to only 359 treated units in phase II/III whereas in phase I, the number of treated units was 1,532 (see Appendix D). The small number of remaining non-traders still perceive trading costs as being prohibitively high.

To sum up the findings of this paper, trading emissions allowances has become a normal business process for most of the participating firms. The first reason for this is the learning effects after 15 years of experience as participants in the European Union Emissions Trading System. The second reason is found in the various revisions of the EU ETS. The ongoing reduction of the cap has had an impact on the market prices in the second part of phase III. This second part of phase III, however, was not investigated in this paper and is still subject to further research. To integrate it and to give an outlook, Figure 6.1 illustrates the evolution of the transaction prices between 2005 and 2020. Phase II included the years of the economic crisis. Especially southern European countries were characterized by the economic crisis. Companies hit by it had lower emissions than their allocated allowances. They were able to bank allowances. All banked allowances were carried over to phase III and resulted in an allocation surplus which led to a price drop at the beginning of phase III. Prices began to rise only from 2018 onwards. Higher prices increase the opportunity costs of holding excess allowances and strengthen the incentive for further emissions reductions.

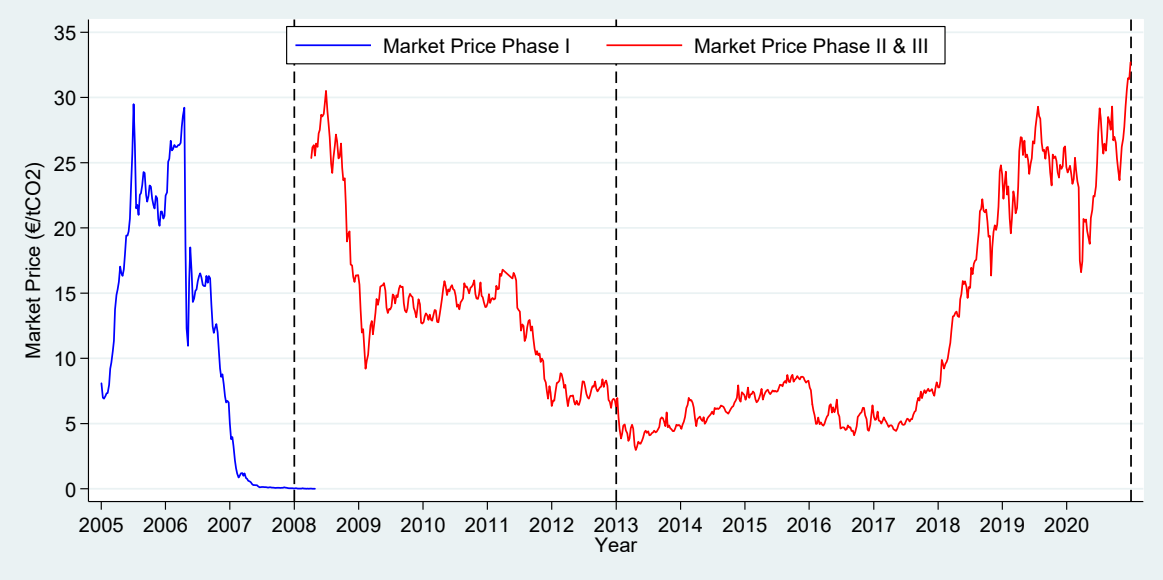


Figure 6.1. Transaction Prices for European Union Emission Allowances for the years 2005 – 2020.

Note: Data Sources: Ember (https://ember-climate.org). Phase I was a pilot phase. Allowances that were not used for compliance purposes could not be carried over to phase II. The vertical dashed lines indicate the three trading phases between 2005 and 2020.

Finally, three points are worth mentioning: (i) The European emissions trading scheme is working. Auctioning instead of free allocation has strengthened the pressure to engage in trading. (ii) Learning effects have led to more trading experience. Since a relatively small number of firms do not participate in trading activities, cost efficiency is increasing. (iii) A small number of smaller emitters, showing long positions, still regard the emissions trading system as regulatory. Their main aim is to be compliant at the end of the compliance cycle. Further research could focus on sectoral analysis, probably by using individual transaction and daily price data instead of annual data. Other research is open to analyze the impact of auctioning on the trading behavior. As auctioning is going to be the default in the upcoming fourth phase, research in this direction could be helpful.

References

BEHRINGER, J.-M., BLEUEL, M. & HILLEBRAND, B. 2006. Der Handel mit CO2- Emissionsberechtigungen - erste Erfahrungen und Konsequenzen. Berlin, Münster: EEFA – Energy Environment Forecast Analysis GmbH.

BETZ, R., SANDERSON, T. & ANCEV, T. 2010. In or out: efficient inclusion of installations in an emissions trading scheme? *Journal of Regulatory Economics,* 37**,** 162-179.

CHAMBERLAIN, G. 1984. Panel data. *Handbook of econometrics,* 2**,** 1247-1318.

CLUDIUS, J. 2016. The EUTL Transfer Dataset. Description and Insights. *Zurich University of Applied Sciences,* Working Paper No. 9.

EUROPEAN UNION. 2003. *EU Directive No 2003/87 establishing a Scheme for Greenhouse Gas Emission Allowance Trading* [Online]. European Commission Available: http://data.europa.eu/eli/dir/2003/87/oj [Accessed].

EUROPEAN UNION. 2013. *Commission Regulation (EU) No 389/2013 establishing a Union Registry* [Online]. European Commission Available: http://data.europa.eu/eli/reg/2013/389/oj [Accessed].

EUROPEAN UNION. 2015. *EU ETS Handbook* [Online]. European Commission Available: https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf [Accessed].

FRUNZA, M.-C. 2013. *Fraud and carbon markets: The carbon connection*, Routledge.

GRAUS, W. & VOOGT, M. 2007. Small installations within the EU Emissions Trading Scheme. *Report under the project "Review of EU Emissions Trading Scheme", ECS04079, Report commissioned by the European Commission Directorate General for Environment, Brussels.* Ecofys.

HEINDL, P. 2012. Transaction costs and tradable permits: Empirical evidence from the EU emissions trading scheme. *ZEW-Centre for European Economic Research Discussion Paper*.

JARAITĖ-KAŽUKAUSKĖ, J. & KAŽUKAUSKAS, A. 2015. Do transaction costs influence firm trading behaviour in the european emissions trading system? *Environmental and Resource Economics,* 62**,** 583-613.

JARAITĖ, J., CONVERY, F. & DI MARIA, C. 2010. Transaction costs for firms in the EU ETS: lessons from Ireland. *Climate Policy,* 10**,** 190-215.

MARTIN, R., MUÛLS, M. & WAGNER, U. J. 2014. Trading behavior in the EU Emissions Trading Scheme. *Available at SSRN 2362810*.

MONTGOMERY, W. D. 1972. Markets in licenses and efficient pollution control programs. *Journal of economic theory,* 5**,** 395-418.

MUNDLAK, Y. 1978. On the pooling of time series and cross section data. *Econometrica: journal of the Econometric Society***,** 69-85.

ROSENBAUM, P. R. & RUBIN, D. B. 1985. Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician,* 39**,** 33-38.

STAVINS, R. N. 1995. Transaction costs and tradeable permits. *Journal of environmental economics and management,* 29**,** 133-148.

Appendices

Appendix A. Construction of the panel dataset[10]

1. Operator Holding Accounts

Every participating installation must hold an operator holding account where all its transactions and compliance data is stored. As mentioned before, significant changes were introduced for the third trading period. One of the changes was that the EU ETS introduced a new registry system for the third phase. This included new account IDs for operator and personal holding accounts. Former accounts from phases I and II were closed and new accounts were opened. Compliance data was transferred to new accounts system as well as banked allowances (see Table 2.1). It is not possible to track the installations using the old and new account IDs since there is no linkage between the two IDs. However, linking the records of phases I and II with the records of phase III is possible using the account name as an identifier. A side effect of this linking is the aggregation process of the installations over the account name. Installations with the same account name will form a managing unit which I will from now on refer to as "firm". According to Cludius (2016) this analysis is, therefore, conducted on level one aggregation.

Since every emitting participant must be compliant at the end of every compliance year, other account types than operator holding accounts were dropped from the accounts' dataset[11]. All aircraft operators were excluded too, since they had only been included in the EU ETS since January 2012 and can, therefore, not be compared with observations from phase I and II[12]. In order to further clean the account dataset, accounts with empty compliance data either in allocated allowances, surrendered allowances or verified emissions in every year between the years 2005-2014 were dropped from the dataset. This resulted in 1.584 observations having been deleted. I also dropped installations that opened an account in 2015 or later or had already closed it in the first phase of the EU ETS between 2005 to 2007. These 128 accounts were deleted because their opening and closing date were outside the data range of this analysis. 1,330 accounts could not be assigned to the account holder since their account names were not differentiable[13].

The final account dataset comprises the accounts from all three phases between 2005 and 2014. It covers a total of 12,245 firms and a timespan of 10 years. 5,473 firms can be tracked over the whole range, since they had always been active between 2005 and 2014. 5'837 firms have enough data to be tracked in phase I and phase III. Figure 0.1 graphically displays the assignment of the firms in the dataset to the three EU ETS phases.

[10] The original data from the EUTL was provided by Jan Abrell, senior researcher of the ZEW.

[11] A description of the relevant account types can be found in Appendix B.

[12] In the EU registry operator holding accounts and former operator holding accounts refer to the account type 100-7 and 120-0, whereas aircraft operators refer to the account type 100-8.

[13] This was the case for operator holding account names that were only named operator account. It only occurred to operator holding accounts from the countries GB, IT, IE and RO.

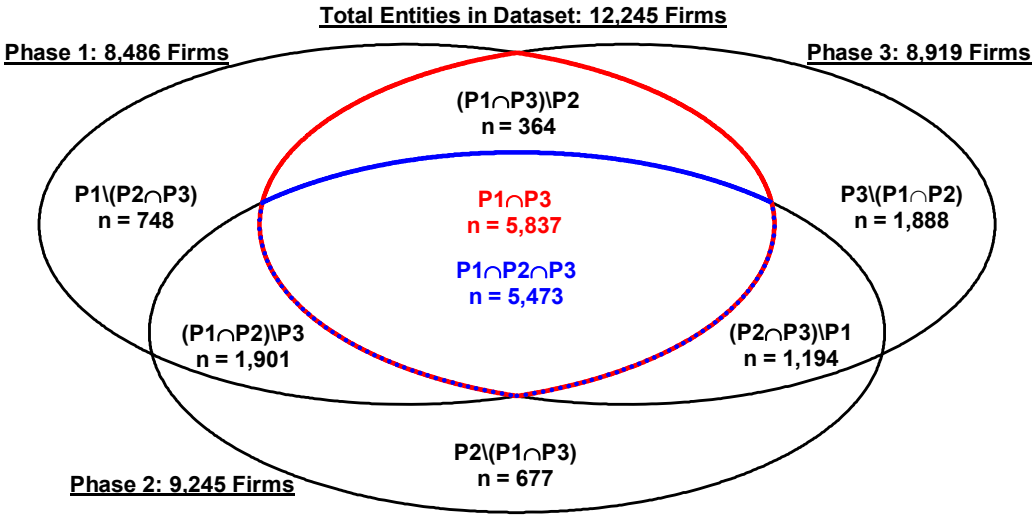


Figure 0.1. Assignment of the firms in the EU ETS to the three phases.

In order to be able to compare phase I and II with phase III operators, the new EU ETS activity types of all stationary installations were transformed back into the ten categories used for phase I and phase II of the EU ETS according to the European Union (2003) Directive[14]. The translation scheme can be found in Appendix C. Also, the number of installations per firm was calculated out of the number of installations with the same account name when aggregating the data. Several additional variables and dummies have been included. They are explained whenever they are first being mentioned in the paper.

2. Transactions

As already explained in Table 2.1, auction instead of free allocation had become more and more the standard by 2012. This results in an increasing number of transactions from 2012 onwards. By identifying auction delivery accounts in the transaction data, it is possible to track auction transfers which lead directly to an operator holding account. Thus, a distinction can be made between auction transactions (primary market) and market transactions (secondary market). However, most auction transactions are not transferred to operator holding accounts but to person holding accounts. From these accounts they enter the secondary market and are treated as regular market transactions. In the trading data for 2012, 2013 and 2014 some transactions between the same old operator holding accounts (120-0) and the new operator holding accounts (107-0) were identified as carry over of banked allowances between phase II and phase III. Intra-firm transactions can be identified as transactions between accounts with the same account holder name. With this additional information, it is possible to distinguish between pure market transactions and intra-firm transactions. With the term "year" I refer to the compliance cycle in the EU ETS. A compliance cycle starts on May 1 and ends on April 30 of the next calendar year. The timeframe is defined this way as the verified emissions for the previous year must be declared to the authorities by March 31 and, finally, allowances must be surrendered by April 30. Therefore, a compliance process starts on May 1 with new allocated allowances on February 28. Detailed information of the compliance cycle can be found in the EU ETS Handbook on page 101 (European Union, 2015). Transferring transactions (market sales, intra sales) and acquiring transactions (market purchases, intra purchases, auction purchases) are created separately and finally merged to a transaction dataset. This dataset is then, in turn, merged with the accounts dataset described in the previous section by the account ID and, finally, aggregated to firm level by account name and registry code. The final dataset, including all compliance as well as transaction data on firm level, consists of 122,450 observations, aggregated on firm level one, and comprises a period of 10 compliance years.

[14] See Annex I of the European Union Directive 2003/87: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003L0087#d1e32-42-1

Appendix B. Description of Account Types.

Account Type	Description
100-12	Trading Account
100-7	Operator Holding Account
100-8	Person Holding Account
100-9	Aircraft Operator Account
120-0	Former Operator Holding Account
121-0	Person Account in National Registry

Appendix C. Translation scheme of activities types (phase III: 2013-2020) and sectors (phase I & II: 2005-2012).

Activities	Sectors	Share of firms (%)
20 Combustion of fuels	Combustion > 20 MW	62.56
21 Refining of mineral oil	Mineral Oil Refineries	1.09
22 Production of coke	Coke Ovens	0.17
23 Metal ore roasting or sintering	Metal Ore Roasting or Sintering	0.10
24 Production of pig iron or steel 25 Production or processing of ferrous metals 26 Production of primary aluminium 27 Production of secondary aluminium 28 Production or processing of non-ferrous metals	Pig Iron or Steel	4.79
29 Production of cement clinker 30 Production of lime, or calcination of dolomite/magnesite	Cement and Lime	3.88
31 Manufacture of glass	Glass and Glass Fibre	3.17
32 Manufacture of ceramics 33 Manufacture of mineral wool 34 Production or processing of gypsum or plasterboard	Ceramics, Bricks, Stoneware and Porcelain	13.16
35 Production of pulp 36 Production of paper or cardboard	Pulp and Paper	6.00
37 Production of carbon black 38 Production of nitric acid 39 Production of adipic acid 40 Production of glyoxal and glyoxylic acid 41 Production of ammonia 42 Production of bulk chemicals 43 Production of hydrogen and synthesis gas 44 Production of soda ash and sodium bicarbonate	Chemicals	3.10
45 Capture of greenhouse gases under Directive 2009/31/EC 46 Transport of greenhouse gases under Directive 2009/31/EC 99 Other activity opted-in under Art. 24	Other activity opted-in under Art. 24	1.99

Appendix D. Results of the Logistic Regression Model (left panel: phase I, right panel: phase II / III).

Dep. Variable: Treatment (yes/no) VARIABLES	Logit Phase I
Log(1 + Emissions)	0.206**
	(0.0359)
Log(1 + Total Position)	-0.516**
	(0.0418)
Constant	2.541**
	(0.366)
Observations	2,875
Sector Controls	YES
Country Controls	YES
Pseudo R-squared	0.171

Standard errors in parentheses
** p<0.01, * p<0.05, + p<0.1

Dep. Variable: Treatment (yes/no) VARIABLES	Logit Phase II / III
Log(1 + Emissions)	0.190**
	(0.0611)
Log(1 + Total Position)	-0.505**
	(0.0662)
Constant	4.182**
	(1.018)
Observations	607
Sector Controls	YES
Country Controls	YES
Pseudo R-squared	0.185

Standard errors in parentheses
** p<0.01, * p<0.05, + p<0.1

Treatment assignment	Off support	On support	Total
Untreated	0	1,327	1,327
Treated	16	1,532	1,548
Total	16	2,859	2,875

Treatment assignment	Off support	On support	Total
Untreated	0	245	245
Treated	3	359	362
Total	3	604	607

Variable	Unmatched / Matched	Mean Treated	Mean Control	%bias	%reduct |bias|	t-test t	t-test p>|t|	V(T)/V(C)
ln_emissions	U	9.6007	9.6447	-2.0		-0.54	0.591	0.97
	M	9.6211	9.5154	4.8	-140.6	1.38	0.167	1.08
ln_postot	U	9.5702	10.132	-32.3		-8.60	0.000	1.22*
	M	9.6054	9.5721	1.9	94.1	0.52	0.603	1.05

Variable	Unmatched / Matched	Mean Treated	Mean Control	%bias	%reduct |bias|	t-test t	t-test p>|t|	V(T)/V(C)
ln_emissions	U	8.2388	8.0394	9.9		1.21	0.228	0.86
	M	8.2314	7.7407	24.4	-146.1	3.31	0.001	0.91
ln_postot	U	8.7598	10.047	-68.5		-8.15	0.000	1.38*
	M	8.7828	8.3479	23.1	66.2	2.61	0.009	0.68*