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Offset Credits in the EU ETS: A Quantile Estimation of Firm-Level Transaction Costs

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Abstract

International offset certificates trade at lower prices than European Union Allowances (EUAs), although they are substitutes within the EU Emissions Trading System (EU ETS) for CO_2. Firms therefore had a strong incentive to use the cheaper certificates. However, a considerable number of firms did not use their allowed offset quota and, by doing so, seemingly forwent profits. While most of the literature on emissions trading evaluates the efficiency of regulation in a frictionless world, in practice firms incur costs when complying with regulation. In order to assess the relevance of managerial and information-related transaction costs, this study examines the use of international offset credits in the EU ETS. It establishes a model of firm decision under fixed entry costs and estimates the size of transaction costs rationalizing firm behavior using semi-parametric binary quantile regressions. Comparing binary quantile results with probit estimates shows that high average transaction cost result from a strongly skewed underlying distribution. I find that for most firms the bulk of transaction costs stems from participation in the EU ETS in general, rather than additional participation in the offset trade.

JEL : C25, D23, H23, Q58.

Keywords : Environmental policy, EU ETS, emissions trading, transaction costs, binary quantile estimation.

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1 Introduction

The objective of the EU Emissions Trading System (EU ETS) is to achieve the EU's carbon emission goals at minimum cost. Instead of imposing a fixed tax, the policy determines an emission level and lets the market determine the equilibrium price. Ideally, this system ensures that all firms incur the same price for emissions, and abatement should be realized where it is cheapest, such that the aggregate abatement cost is minimized. However, abatement costs are not the only costs arising from an emissions trading scheme: just like any other regulation, this policy has to be implemented and managed by firms, causing a wide range of administrative, managerial and information-related transaction costs. Typically, such transaction costs are unobserved by the econometrician. Presumably, many firms themselves do not account explicitly for the value of their employees' time and resources spent in the course of EU ETS compliance and optimization. This study uses firm-level data to estimate such transaction costs and argues that their magnitude is relevant for some of the regulated firms and should be taken into account when assessing the efficiency of the EU ETS.

To identify transaction costs, I exploit an important aspect of EU ETS regulation: the possibility to use not only European certificates but also international offset credits. The EU ETS has been linked to the international certificate market created through the Kyoto framework. On aggregate, these additional foreign certificates increase the cap for European polluters and decrease their compliance cost. Offset credits have been cheaper than European credits (European Union Allowances, EAUs) throughout Phase II of the EU ETS (2008-2012). The quantity of offset credits used in the EU is limited by a firm-specific offset quota (*entitlement*) fixed by the regulator. For the firms, offset usage was an unambiguous way to reduce compliance cost. Nevertheless, a considerable share of regulated firms did not use any offset credits.

This study brings together elements, on the one hand, from literature on the use of offset certificates in the EU ETS (Trotignon, 2012a; Ellerman et al., 2014) and, on the other hand, theoretical literature on the impact of transaction costs on emissions trading (Stavins, 1995; Montero, 1998). Moreover, this research relates to contingent valuation theory and uses binary quantile methodology (Kordas, 2006; Belluzzo Jr, 2004).

While the abatement incentives of cap-and-trade schemes have been amply discussed, most of the literature does not consider transaction costs and other frictions arising from practical management of compliance. However, emissions trading – just like any other market transaction – is unlikely to be completely free of transaction costs. In his seminal paper, Coase (1960) underlines that the irrelevancy of initial property allocation for final resource allocation holds only if frictions are negligible. The theoretical importance for cap-and-trade regulation of such frictional "costs to use the price mechanism" is modeled by Stavins (1995) and Montero (1998). Stavins (1995) shows that a major problem arising from transaction costs is that they make the initial allocation non-neutral, such that free allocation (like in Phase II of the EU ETS) has an impact on the resulting market equilibrium outcome. Montero (1998) moreover adds the impact of uncertainty and technology constraints.

Empirical evidence on transaction costs in environmental policy is relatively scarce, as McCann et al. (2005) note in their literature review on this topic: transaction costs are rarely evaluated, maybe simply because of their latent unobservable nature. Literature suggests that transaction costs and other market imperfections have hampered the impact of US environmental trading programs (Tietenberg, 2006; Hahn and Hester, 1989). For example, Atkinson and Tietenberg (1991) argue that trading has been too scarce to reach a cost-efficient outcome; they claim that this inefficiency stems from the bilateral, sequential nature of trades leading to frictions (and thus transaction costs in a broad sense).

Concerning the EU ETS, the literature generally finds that small firms trade more "passively" and that many firms seem to lack institutional capacity for optimal trading (Sandoff and Schaad, 2009). A common strategy among German SMEs is to trade only at the end of the year and *only if* the grandfathered allocation is not sufficient (Loeschel et al., 2011). Surveys show that large emitters set up more sophisticated structures to optimize their compliance and face smaller per-tonne transaction costs (Heindl, 2012; Jaraite and Kazukauskas, 2012; Loeschel et al., 2010, 2011). Similarly supporting the idea of fixed costs, Jaraite et al. (2010) estimate that *per tonne* participation costs of the largest firms were €0.05 per tonne of emissions, while they were up to €2 per tonne for small firms. Schleich and Betz (2004) underline that allocations are so generous that the average need for additional permits for SMEs is only about 1,250 tCO2e per year, an amount at which participation costs are likely to be higher than the actual certificate cost. Virtually all empirical work on transaction costs in the EU ETS is based on survey-data, except Jaraite and Kazukauskas (2012) who use transaction data from Phase I (2005-2007), the test phase of the policy. They claim that transaction costs were a substantial factor stopping firms from actively trading EUAs, but they do not estimate their magnitude. The observed trading pattern is consistent with the existence of entry costs: it appears that firms trade rarely and most transactions take place between plants belonging to the same firm (Zaklan, 2012; Jaraite and Kazukauskas, 2012).[1]

Rather than using survey data, I use administrative data on firm behavior. Anderson and Sallee (2011) identify marginal costs of regulating fuel-standards by observing to what extent car producers use a regulatory loophole of known costs to avoid the fuel-efficiency standards. Conceptually, this is close to the present study which identifies fixed costs by observing what benefits firms forwent in order to avoid trading. Using binary choice to identify a latent variable, this study relates to the revealed-preference methodology used in (nonmarket) contingent valuation of environmental goods (e.g. Bennett and Blamey, 2001). Quantile models have been developed by Koenker and Bassett (1978), but have only recently been applied to binary choice by Kordas (2006). Belluzzo Jr (2004) uses them to estimate the distribution of willingness-to-pay for a public good, which is analogous to the present study: transaction costs are measured here from the observed "unwillingness-to-benefit" of firms.

While the previously cited literature examines trading schemes with only one type of certificates, the literature on linked schemes with two certificate types is limited. Trotignon (2012b) describes how offsets have been used in the EU ETS and shows that firms initially used few offsets until 2011, when there was a sharp increase. He estimates the cumulated savings of firms at €1.5 billion. An aggregate view going up to the end of Phase II in 2012 is provided by Ellerman et al. (2014).

This study provides both a descriptive and an analytical contribution to the literature. First, it describes the observed offset usage behavior. Among firms that failed to participate in the offset market, there are mostly small firms and more particularly those firms with relatively generous free allocations of European certificates. Across all firms, forgone revenue adds up to around €1.37 billion. In a second step, I argue that firms' reluctance to participate can be explained by transaction costs. Without such unobserved transaction costs, the offset entitlement would be an unequivocal "free lunch" opportunity. The large share of firms forgoing these profits can only be rationalized by the interference of some unobserved frictions: transaction costs, as defined in this study, can include employees' time/salaries,

[1]However, transaction data needed for such analysis is only available for the Phase I of the EU ETS.

training and consultancy costs. They are assumed fixed and payable whenever a firm first decides to engage in offset trading or emissions trading in general; therefore, they might also be called "entry costs".

The theoretical section lays out how transaction costs change the firms' optimization problem. It builds on Stavins (1995), however I introduce a second type of certificates and simplify by accounting only for fixed transaction costs. It establishes that such costs can make the firms' free allocation of permits non-neutral, as firms with allocations larger than their emission do not *need* to engage in emissions trading: they can avoid transaction costs of active trading, such that they are less likely to use their offset entitlement. The model establishes a link between, on one hand, the decision to participate in the offset market and, on the other hand, both the initial allocation status and the potential benefit from offset usage. The fundamental assumption is that a firm renounces the potential benefits from offset trading only if the incurred transaction costs are higher than these benefits.

The empirical section uses this insight to estimate the latent transaction costs necessary to rationalize firms' decision not to participate in the offset market. This is the first study that estimates transaction cost using binary quantile regression. I identify the distribution of two cost components: general transaction cost of trading and offset-specific cost. The empirical results show that participation cost in the offset market is relatively low for most firms with a median of €905. The additional general trading cost is much higher with a median cost of €7,770. However, the estimated distribution of these costs is highly skewed, such that the means are much higher than the medians (€21,519 for average general participation plus €83,675 for offset market participation), resulting from some large outliers. A probit regression of the conditional mean would thus be misleading about the costs faced by the majority of firms. Although these transaction costs are often small compared to other production factors, they make active participation unprofitable for 21% of the firms. For bigger firms, investment in offset certificates remains profitable.

The remainder of this article is organized as follows. After introducing the institutional and legal framework of international offset certificates (Section 2.1), I briefly explain the aggregate impact of offset trading in the EU ETS (Section 2.2) and the definition of transaction costs in this context (Section 2.3). I then set up a model of firm-behavior in the reference case, i.e. without any transaction/entry costs (Section 3.1), which is extended by adding entry costs (Section 3.2). Finally, I present the data and some stylized facts, explain the econometric methodology (Section 4) and present the estimated distribution of transaction costs (Section 5).

2 Background

The EU ETS and the international offset credits are part of a complex regulatory framework. This section briefly explains the key elements of regulation. It further sketches out the aggregate mechanics of introducing a second type of certificates into an emissions trading system. Finally, this section details what sort of costs fall under this study's very broad definition of the term "transaction costs".

2.1 Institutional framework

Each year, the EU issues EU emission allowances (EUAs) that sum up to the overall EU ETS emission cap for that year. In Phase II – the period under study here – virtually all these certificates were distributed free of charge to the regulated firms, according to their historic emission levels (called *grandfathered* allocation). At the end of each year, firms have to report their emissions and hand in (*surrender*) certificates equalling their emissions: one for each tonne of CO_2, hence the use of *tonnes of CO_2 equivalent* (tCO2e) as a unit to measure quantities of certificates. Used certificates disappear from the market, unused certificates remain valid in subsequent years.

In order to coordinate international efforts of emission reduction and to lower abatement cost for EU-based companies, the EU linked the EU ETS to the international framework established by the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol. According to these international conventions, suitable projects that save emissions in unregulated parts of the world (Kyoto "non-Annex I" countries, in practice mostly India and China) can be validated and certified by UNEP Risoe. This procedure then generates of Certified Emission Reductions (CERs, from Clean Development Mechanism (CDM)) or Emission Reduction Units (ERUs, from Joint Implementation projects (JI)), which can be used to justify emissions in regulated parts of the world such as EU countries. CERs and ERUs are commonly called *international offset certificates*.[2] Note that there is no free distribution of these offsets, such that firms need to actively acquire them.

Within their obligations from the EU ETS, firms could substitute a limited amount of European certificates with such offset certificates. Such a substitution was attractive because offset certificates are generally cheaper than EUAs. However, to ensure that the bulk of emission reduction is achieved domestically, the EU restricts the quantity of offsets usable by each firm. The exact definition of this quota depends on the national government, but most countries use a percentage share of 10 to 20% of the grandfathered allocation as a benchmark, cf. Table 4 on page 26 in the Appendix, yielding a firm-specific offset entitlement.

These quantity limits for offset use were set upfront for Phase II. In the middle of Phase II (April 2009), an EU directive[3] announced that the usage limits of certain offsets should be transferable (*bankable*) into Phase III (2013-2020), however it was unclear what amounts and which types of certificates.[4] Due to institutional obstacles, the final regulation ensuring the bankability and its conditions only appeared in November 2013,[5] i.e. *after* the original claim on Phase II expired. The present study therefore considers the end of Phase II to be the temporal limit of offset use.

The present study only examines the demand side of offset certificates. One possible alternative explanation for limited offset use would be that offset use was limited by supply side constraints. However, the central registry of the UNEP shows that the number of offsets generated until the end of 2012 was much higher than aggregate offset usage rights within the EU.[6] Market data shows that offset prices collapsed to virtually zero after the end of Phase II, which shows that the EU ETS demand

[2]As CERs and ERUs can be used interchangeably under this legislation, I will from now on only use the term "offsets" while everything applies equally to CERs and ERUs.

[3]Directive 2009/29/EC

[4]Offset certificates have been criticized because they rely on the fundamental criterion of *additionality*, which is virtually impossible to ensure completely. Some types of certificates, in particular those from "industrial gas" projects, seem too easily manipulated such that they are not further accepted in Phase III of the EU ETS.

[5]Commission Regulation (EU) No 1123/2013

[6]Theoretically, in addition to EU firm-level demand (analyzed in this study) there was scope for additional demand coming from the state-level; however, at the state-level of the Kyoto framework, offsets were perfect substitutes for Assigned Amount Units (AAUs). These certificates are traded infrequently and bilaterally, mostly directly between participating states, such that there is no transparent market price. However, given the large AAU overallocation of ex-Soviet Union states (so-called "hot air"), the evidence suggests that AAUs are sold usually far below the price of EUAs, CERs and ERUs (Aldrich and Koerner, 2012).

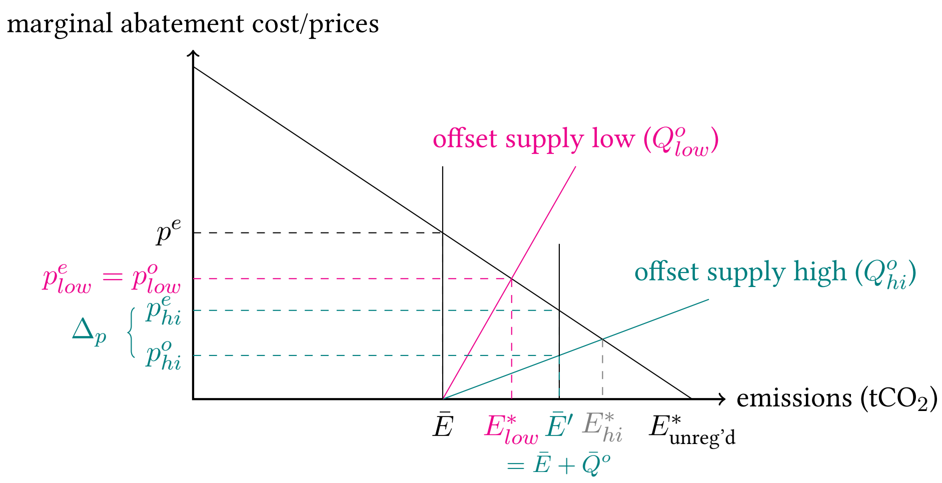


Figure 1: Aggregate market equilibrium, with two alternative offset supply levels

was the driving force behind offset valuation.

2.2 Why are offset certificates cheaper? – Theory of the aggregate impact of offset credits

International offset credits cover emissions from geographic regions that are not previously included in the scope of EU ETS. As such, they are a *spatial flexibility mechanism* (Stevens and Rose, 2002) allowing firms to abate where it is cheapest (other countries, especially developing countries) and have the abatement credited via the creation of offset credits. The creation of offset certificates increases the overall cap imposed by the EU ETS. Potentially, the cap could increase by an amount equal to the sum of all firms' offset entitlements. In practice, it depends on prices whether the regulatory offset quantity limit or the supply of offset certificates determines the overall amount of certificates available.

The resulting market equilibrium is illustrated in Figure 1: in an unregulated situation, emissions have no cost and firms emit $E^*_{\text{unreg'd}}$. Without offset credits, the standard result for emissions trading holds: the market clears at the regulated maximum emission level $\bar{E}$ at price p^e, equal to the marginal abatement cost at $\bar{E}$ (Trotignon, 2012b). Offset certificates are perfect substitutes for EUAs up to the regulatory quantity limit. When offsets are costly to produce (supply Q^o_{low}), their availability increases the overall cap, lowers the price and moves the equilibrium to E^*_{low}, where prices are set at the level for which offset supply clears. This equalizes EUA and offset prices $p^e_{low} = p^o_{low}$. When offset creation is cheap (supply Q^o_{hi}), firms would like to buy more offset certificates than allowed and pollute up to emission level E^*_{hi}. The aggregate offset quantity limit $\bar{Q}^o$ is binding in that case. The resulting constrained equilibrium at $\bar{E}'$, does not ensure equal prices anymore: EUAs trade at marginal abatement cost p^e_{hi} of the new emission level $\bar{E}' = \bar{E} + \bar{Q}^o$. The over-supply of offset certificates drives their price down to p^o_{hi}.

Thus, the price differential $\Delta_p = p^e - p^o$ is always positive or at least zero; its magnitude depends on the difficulty to generate offsets and on the stringency of the offset usage quantity limit. Note that even if EUA and offset prices are not equalized, the introduction of offset credits nevertheless reduces EUA prices from p^e to p^e_{hi}.

	Average transaction costs	Cost structure	Scope
Heindl (2012)	€4,193 (information)	Fixed + variable	Germany
	€4,659 (trading)		
	€12,223 (all, including MRV)		
Jaraite et al. (2010)	€146,040 (all, including MRV)	Variable	Ireland
Loeschel et al. (2010)	€1.79/tCO2e if emissions $<$ 25,000t	Variable	Germany
	€0.36/tCO2e if emissions $\geq$ 25,000t		
Loeschel et al. (2011)	€8,136 (all, including MRV)	Fixed + variable	Germany
	of which €2,034 for information and trading		

Table 1: Overview of transaction cost estimates in the EU ETS in the literature [8]

2.3 Definition of transaction costs

Beyond the direct cost of the emission certificates, the EU ETS causes a number of information-related and management frictions which I summarize under the term transaction costs. As Heindl (2012) explains, the EU ETS produces costs through different channels:

- Costs from monitoring, reporting and validating emissions (MRV);
- Service charges of the EU registry and other formal administrative costs;
- Salaries of people employed by the firm for trading and information gathering and forecasting of allowance prices, and
- Costs induced by finding trading partners, bargaining, contracting and managing price risk.

The first two sources of participation costs are unavoidable and should thus not explain firms' non-participation in the offset market. The latter two sources of participation costs are directly related to firms' active trading participation and might explain why firms do not venture into the offset market. In the following, the term transaction cost is defined as costs arising from trade (direct transaction costs) and from information gathering about market structure and management (indirect costs); it is likely to include personnel salaries, recruiting cost, consulting fees, etc. It *does not* include monitoring and reporting of emissions, administrative cost for EU/national agencies, and generally any other "unavoidable" cost. This study does not differentiate between internal costs and external consultancy costs. This is a more narrow definition than in some other work which considers the overall cost of establishing, managing, monitoring and enforcing a policy (Krutilla and Krause, 2010; Joas and Flachsland, 2014).[7]

Heindl (2012) finds that information-procurement alone – the biggest upfront cost to entering active trading – costs firms about 17 employee-workdays. He also finds that information and trading costs do not depend on firm size. Most surveys present their results at a per-tonne basis, i.e. interpreting them as variable (rather than fixed) costs, cf. Table 1.

Typically, these transaction costs are unobserved. However, they clearly exist. A multitude of news and data providers (Point Carbon), consulting firms (ICIS/Tschach) and financial transaction services (brokerage like TFS Green, exchange platforms like ICE) have emerged. The fact that firms use such costly services indicates that there must be an information problem. Moreover, descriptive

[7] In particular, this study concentrates on firms' costs and does not take into account what Joas and Flachsland (2014) call "public-sector costs" incurred by the regulatory authority.

[8] Mostly own computation from estimated parameters stated in the original studies.

management literature highlights the discrepancy between actual and intended market practice, with firms use simple heuristics instead of full optimization and show reluctance to trade (e.g. Veal and Mouzas, 2012). As the final transaction is virtually cost-free, transaction costs are in this context largely due to upfront costs of information procurement. Just as an example, setting up a trading account at the ICE – the biggest exchange, clearing about 90% of emission certificate trade in Europe – costs €2,500 in direct fees,[9] while an individual transaction thereafter costs only cents.[10][11]

3 Model

First, a static model describes firm's optimization problem in presence of two types of emission certificates without transaction costs. In a second step, I examine how optimal behavior changes in presence of fixed transaction costs. Simply put, firms always want to use offset credits, unless transaction costs are prohibitively high compared to potential profits from using the cheaper offset credits.

3.1 Emissions trading with offset credits: least-cost scenario

For the purpose of this study, it is useful to look at firms' optimization problem aggregated over Phase II, which is qualitatively equivalent to looking just at the last year of offset validity.[12]As a reference case, this subsection examines emissions trading with two types of certificates *without* participation costs. I show that firms can separate the decision of optimal emission levels (and produced quantities) from the partitioning between European and offset certificates. This point considerably simplifies the analysis in the subsequent section 3.2, where we concentrate on the latter decision.

In absence of offsets, it has been shown (e.g. by Montgomery, 1972) that there is a market equilibrium ensuring that marginal abatement cost is constant across firms and equal to the EUA price p^e. The present model adds a second type of certificates, such that each firm i solves the following optimization problem:

$$\max_{Y_i, E_i, Q_i^e} \pi = pY_i - C(Y_i, E_i) - T(Q_i^o, Q_i^e) + p^e A_i, \tag{1}$$

$$\text{subject to } E_i = Q_i^o + Q_i^e, \tag{2}$$

$$T(Q_i^o, Q_i^e) = p^o Q_i^o + p^e Q_i^e, \tag{3}$$

$$Q_i^o \leq K_i, \tag{4}$$

where equation (1) is the profit maximization with $C(Y_i, E_i)$ the production cost, which depends

[9]As indicated on https://www.theice.com/fees (March 1,2015)

[10]Convery and Redmond (2007) establish a list of direct transaction fees: brokers have relatively large minimum trade sizes and take between 1 and 5 cent fee per certificate (tCO2e). Exchanges take smaller trades and charge between 0.5 and 3 cent per certificate.

[11]Note that in theory transaction costs could also consist in the actual abatement cost that internationally operating firms could incur if they decide to create offset certificates in their own plants abroad, rather than purchasing the certificates on a market place. This study assumes that the large majority of firms bought their certificates, which is consistent with anecdotal evidence about offsets. This claim cannot be proved however, due to data restrictions. If this claim is not true, the estimations in this study remain valid, but their interpretation changes from transaction/entry costs to inefficiencies in the generation of offsets.

[12]Note that allocations and offset entitlements for the whole period were known to the firms at the beginning of Phase II (from the NAPs).

on emissions E_i and output Y_i.[13] As usual, I assume that increasing production Y_i (at a fixed emission level) increases cost, i.e. $C_Y(Y_i, E_i) > 0$, and reducing emissions (at a given production level) increases cost, $C_E(Y_i, E_i) < 0$.[14] Q_i^o are the offsets used in Phase II and Q_i^e are used EUAs. $T(Q_i^o, Q_i^e)$ is the cost of complying with ETS rules, i.e. the cost of buying the certificate quantities Q_i^e and Q_i^o necessary to cover the emission level E_i (equations (2) and (3)). At the beginning of Phase II, firms are given free allocation of European certificates A_i; they can sell superfluous certificates at market price p^e. The firm-specific constant K_i in equation (4) is the regulated quota for offset usage. The overall amount of EUAs in the market is fixed by total allocations over all firms.

The firm has to solve three problems simultaneously: decide on the optimal produced quantity Y_i, determine the optimal emission level E_i and split compliance (i.e. an amount of certificates equal to E_i) between international offset and European certificates. The first-order conditions require quantity to be chosen optimally given production cost $C(Y_i, E_i)$ and prices. Let us assume that the production function C and prices p are such that there exists a function $Y_i^*(E_i)$ giving the optimal quantity produced for any given emission level at given prices.[15] Compliance cost $T(Q_i^o, Q_i^e)$ results from the cost incurred for both types of certificates. To satisfy the first-order condition for emissions, marginal abatement cost has to be equal to marginal compliance cost:[16]

$$p\frac{\partial Y_i^*(E_i)}{\partial E_i} - \frac{\partial C(Y_i^*(E_i), E_i)}{\partial Y_i^*(E_i)}\frac{\partial Y_i^*(E_i)}{\partial E_i} - \frac{\partial C(Y_i^*(E_i), E_i)}{\partial E_i} = \frac{\partial T}{\partial E_i} \tag{5}$$

$$\left[p - \frac{\partial C(Y_i^*(E_i), E_i)}{\partial Y_i^*(E_i)}\right]\frac{\partial Y_i^*(E_i)}{\partial E_i} - \frac{\partial C(Y_i^*(E_i), E_i)}{\partial E_i} = \frac{\partial T}{\partial E_i} \tag{6}$$

$$-\frac{\partial C(Y_i^*(E_i), E_i)}{\partial E_i} = p^o\frac{\partial Q_i^o}{\partial E_i} + p^e\frac{\partial Q_i^e}{\partial E_i} \tag{7}$$

The compliance cost arises from an optimal partitioning of certificates between EUAs and offsets, given the price differential and the quantity restriction on offsets. The marginal cost is either p^e or p^o depending on which sort of certificate is used to cover the last (marginal) emission. As previously seen, offsets are perfect substitutes for EUAs up to a certain quantity limit; their price is thus at most as high as an EUA's price, but never higher ($p^e - p^o =: \Delta_p \geq 0$).[17]

The result is straightforward and illustrated in Figure 2: as a perfect substitute at a lower price, offset credits are clearly preferable to EUAs, up to the regulated quota (entitlement). Only if emissions are above K_i, the firm complies for remaining emissions by using the more expensive EUAs. Compared to a system with only EUAs, the firm saves an amount equal to $\Delta_p K_i$. The compliance cost can be simplified to $T^*(E_i)$ giving for all emission levels E_i the compliance cost resulting from an optimal split between European and offset certificates. The equation for $T^*(E_i)$ then enters the optimization problem as a constraint:[18]

[13] Emissions E_i and output Y_i as well as all other variables are aggregated over the entire Phase II (2008-2012)

[14] C_Y and C_E denote the partial derivatives with respect to Y and E, respectively.

[15] A competitive market hypothesis simplifies this part, but is not essential to the subsequent argument, as long as there is a single equilibrium quantity $Y^*(E^*)$.

[16] Using the competitive market hypothesis and the envelope theorem to get from equation (6) to (7)).

[17] For the purpose of this study, I only consider situations in which offset certificates are strictly cheaper than EUAs, as the alternative where both prices are equal is qualitatively not different from a system without offsets. Moreover, the data reveals that in practice there has always been a clear price discount for offset certificates.

[18] The profit's last term in equation (1) $p^e A_i$ is a choice-independent lump-sum transfer and can be dropped from the maximization equation.

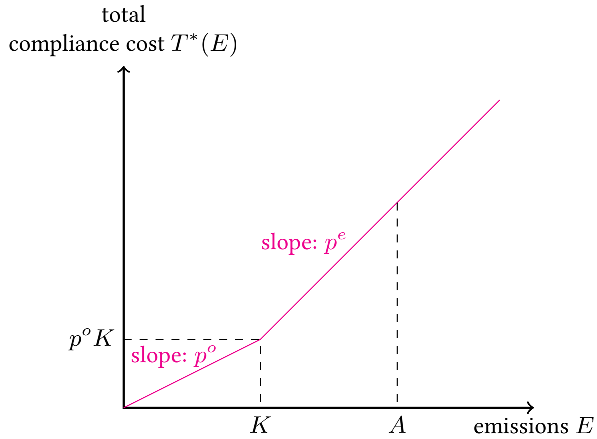


Figure 2: Deciding on the optimal quantity of EUAs and offsets (no entry cost, reference case)

$$\max_{E_i} \pi(Y^*(E_i), E_i) = pY^*(E_i) - C(Y^*(E_i), E_i) - T^*(E_i) \tag{8}$$

$$\text{such that } T^*(E_i) = \begin{cases} p^o E_i, & \text{if } 0 < E_i \leq K_i \\ p^e(E_i - K_i) + p^o K_i, & \text{if } K_i < E_i \end{cases} \tag{9}$$

3.2 Entry costs for both certificate markets

We will now see how fixed participation costs on the offset market change the firm's problem. I assume that firms face some general entry cost to participate in any certificate trading, i.e. the cost of setting up a trading department no matter the type of certificates, and an additional cost to participate in the offset market. They can avoid both costs if they use only their freely allocated European certificates. Firms with optimal emissions bigger than their allocation are forced to buy certificates and cannot avoid the general participation cost. Compliance cost from equation (3) has now two additional terms:

$$T(Q_i^o, Q_i^e, E_i) = p^o Q_i^o + p^e Q_i^e + \mathbb{1}^o T^o + \mathbb{1}^e T^e, \tag{10}$$

$$= p^e E_i + \mathbb{1}^e (T^e + \mathbb{1}^o (T^o - \Delta_p Q_i^o)), \tag{11}$$

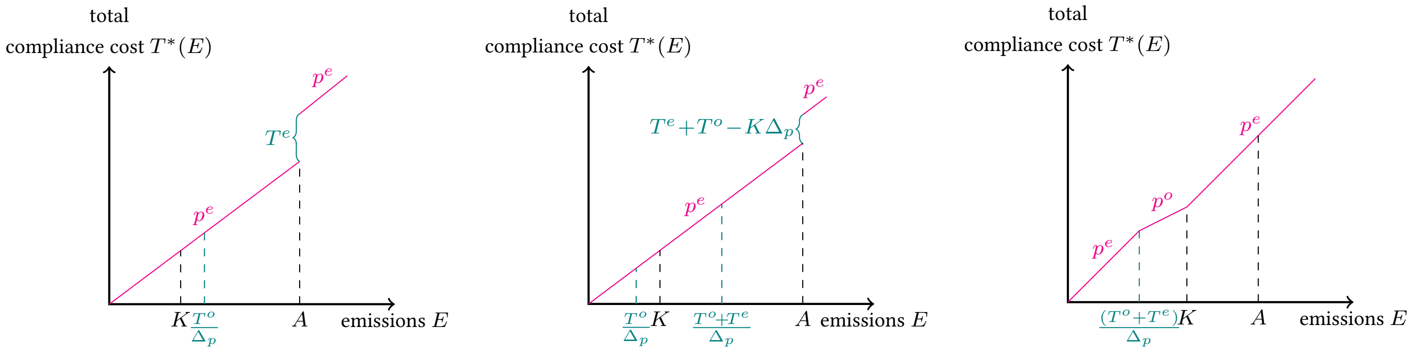
$$\text{where } \mathbb{1}^o = 1 \text{ iff } Q_i^o > 0 \tag{12}$$

$$\mathbb{1}^e = 1 \text{ iff } Q_i^o > 0 \text{ and/or } Q_i^e > A_i \tag{13}$$

where a firm incurs general information entry costs T^e if it buys any certificates, but needs to pay an additional information cost T^o to participate in the less well-known offset market. This specification also implements the idea that firms which are "long" in equilibrium, i.e. which received more free allocations than needed for their optimal emissions ($A_i > E_i^*$), are not obliged to actively trade certificates. "Short" firms need to enter the market to buy some certificates anyways and should thus consider the general participation cost T^e sunk when deciding about offset usage.[19] The impact of

[19] This definition is not ideal: rather than conditioning on firms being forced to trade, one would like to condition on firms actually trading. However, the data does not allow this distinction. As a consequence, the estimate for transaction costs is downward biased.

transaction costs on offset usage and incurred total cost depends on the relative magnitudes of T^o, $T^o + T^e$ and $K_i\Delta_p$.



(a) High entry costs

(b) Intermediary entry costs

(c) Low entry costs

Figure 3: Deciding on the optimal quantity of European and offset certificates (with entry cost on both markets)

Figure 3 illustrates the three possible situations. In Figure 3a, offset entry costs are high such that $T^o > K_i\Delta_p$. In this case, entering the offset market is not useful at any emission level. Firms still have to incur entry cost T^e to enter the EUA market if their emissions are higher than their free allocation, which results in a discontinuity at $E_i = A_i$. In Figure 3b, T^o is relatively low, but $T^o + T^e$ is so high that offsets alone are unprofitable. As $T^o < K_i\Delta_p$, firms which already incur entry price T^e (because $E_i > A_i$) also buy offset certificates. There is thus a similar discontinuity as in 3a, but the jump is reduced from T^e to $T^e + T^o - K_i\Delta_p$, because the firm cashes in some gains from offset usage. Finally, Figure 3c shows the situation if both entry costs are relatively low such that a firm uses offsets as soon as its emissions are above the threshold.

Cases (a) and (b) illustrate situations in which entry costs may make initial allocation non-neutral, as they produce a jump in the cost curve. Following the "Coase theorem", initial allocation does not matter for the final outcome if bargaining is possible and cheap. In presence of transaction cost however, such as in Figure 3, initial allocation has an impact on firms' probability to use offset credits.

The direct effect of participation costs on total compliance cost $T^*(E)$ does not impact the marginal cost-benefit analysis: both above and below A_i, firms face a marginal price of p^e. Even in case (c), the slope of the cost curve is p^e for most firms and only the very exceptional firms face a marginal certificate price of p^o.

Let "allocation status" $\mathbb{1}_i^{long}$ be a dummy variable indicating that allocation A_i is larger than emissions E_i^*, such that optimizing compliance simplifies to the decision whether to use offset certificates:[20]

$$\max_{\{\mathbb{1}_i^o\}} \mathbb{1}_i^o(\Delta_p K_i - T^o - \mathbb{1}_i^{long} T^e) \tag{14}$$
$$\text{where } \mathbb{1}_i^o = 1 \text{ iff } Q_i^o > 0$$

A firm participates if it is worth incurring the entry costs, which depend on the allocation status – long or short – of the firm. The empirical section uses the prediction that a short firm not participating must imply that $\Delta_p K_i < T^o$ and a long firm not participating shows that $\Delta_p K_i < T^o + T^e$, while

[20]See Appendix on page 27 for more details on the potential interaction of transaction costs and allocation status.

the same inequalities are reversed for participating firms. Note that this solution implies an "all-or-nothing" decision as long as entry cost is fixed. Observe as well that in spite of these frictions, marginal abatement cost is equalized across the large majority of firms at the level of p^e, just like in the no-cost reference case.

$$\mathbb{1}_i^o = \begin{cases} 1 & \text{if } \Delta_p K_i > T^o - \mathbb{1}_i^{long} T^e, \\ 0 & \text{otherwise.} \end{cases}$$

An important assumption is that firms take prices as given here: every individual firm is too small to consider its own impact on the price level, i.e. there is no market power on the certificate market. On the aggregate, p^e depends on the number of firms using offset certificates. To the extent that transaction costs reduce access to the offset market, they are not neutral for p^e and thus for Y^* and E^*.[21]

4 Data and empirical research design

I use administrative data from the EU. Descriptive data analysis reveals some stylized facts, that my empirical analysis relies on: (a) offset certificates are indeed cheaper than European certificates, (b) virtually all firms has emissions greater than their offset entitlement and many of them smaller than their free allocation, (c) a non-negligible number of firms does not use their offset entitlements (22%) and (d) the size distribution of firms is very unequal.

4.1 Data sources

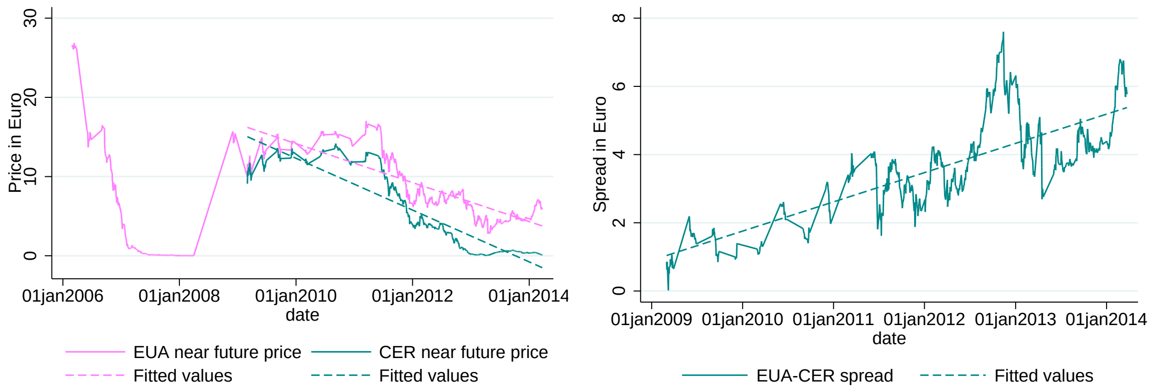
This study mainly relies on the data of the European ETS Registry (European Union Transaction Log, EUTL) which is a compilation of member states' national registries of Phase I and II (2005-2012). This comprehensive administrative data comprises the allocated EUAs, verified emissions and used (*surrendered*) certificates (EUAs, CERs and ERUs) for *all* 13,590 plants subject to ETS compliance obligations in Phase II. Moreover, a matching with Bureau van Dijk's Orbis company database reveals ownership structures that link many of these individual plants.[22] This matching is important as the relevant decision is likely to happen at the firm level, even though regulation, allocation and offset entitlements are defined at plant level. After some data cleaning,[23] there remain around 9,000 plants belonging to 4,578 firms. Over half of the plants belong to firms owning just one plant.

The plant-specific offset quantity limit K_i is the product of a nation-specific offset quota multiplied by the plant's free allocations A_i over Phase II. The magnitude of this quota has been chosen by national governments, but the EU has restricted the maximum to 22%, as implemented in Germany or Spain. For the purpose of this study, the limits have been computed by this rule and verified using the International Credit Entitlement tables published by the EUTL in 2014. Allocations have been relatively generous

[21]There are second-order effects as well, as participation costs impact the demand for offsets: this decreases the offset price p^o and increases the EUA price p^e. While these price effects are essential for a general equilibrium and welfare assessment, they are not informative on transaction costs and are beyond the scope of this study.

[22]For more information on this matching, see Jaraite et al. (2013) or their website http://fsr.eui.eu/CPRU/EUTLTransactionData.aspx

[23]Plants from countries that do not participate in the standard way described in Section 2.1 (Estonia, Iceland, Lithuania, Liechtenstein, Malta and Norway; 220 plants) and some which have offset-use beyond the legal limit (most likely because of merger and acquisition transactions which are unobserved in this data set; 94 plants) are excluded. Around 3,000 plants never register any emission or cease existing in 2011 and 2012, so they are excluded as well.



(a) Prices of EUAs and CERs on the secondary market (b) EUA-CER price spread

Figure 4: Prices of EU certificates and offsets (source: www.theice.com)

such that 80% of the firms could cover all of their emissions using only grandfathered allocations (they will further be called "long" firms). However, offset entitlement K_i has been so small that only a meager 2.8% of firms is able to comply by using offsets only. Table 2 shows that free allocation has on average been just above emissions. Firms have a wide variety of sizes, with some firms owning up to 158 plants and being active in 11 sectors or 17 countries.

	Mean	Median	SD	Min	Max
Number of countries active	1.13	1	.728	1	17
Number of plants	1.88	1	5.03	1	158
Number of sectors active (NACE definition)	1.12	1	.566	1	11
Free allocated EUAs (ktCO2e)	1,975	112	13,831	.015	380,586
Emissions (ktCO2)	1,919	78.5	16,148	.003	563,608
International credit entitlement (ktCO2e)	272	12	2,335	.001	91,537
Used offset credits (ktCO2e)	208	8.34	1,494	0	55,536
Savings from offset use (k €)	799	31.2	5,836	0	217,412
Unexploited profits from offsets (k €)	627	22	7,370	.00465	200,316
Firms using all offset entitlement (in %)	50.5				
Firms using no offsets (in %)	22				
Observations	4578				

Table 2: Descriptive firm statistics

4.2 Price spread and realized savings

Theoretically, offsets are expected to trade at a lower price compared to EUAs or at best at equal price if the offset supply is relatively scarce. Indeed, offsets have always traded at a positive discount from EUAs. Figure 4 shows that the price differential was rather small in the beginning. After few months, the spread became clearer and offsets have been up to €7 cheaper than EUAs. The spread increased with time and was rather volatile. On average the price difference was €3.60.

This price spread has allowed firms to achieve considerable savings,[24] reaching €217.4 million for

[24]Savings are approximated by multiplying the annual average price spread with the amount of offset certificates used in that year, because the actual transaction details (date/price) are not observed.

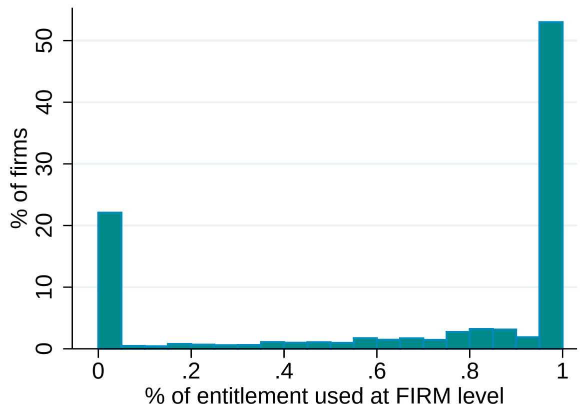


Figure 5: Ratio of used offset credits over overall offset entitlement (source: EUTL and own computations)

the largest firm.Altogether, firms have saved an overall amount of €3.6 billion. However, the aggregate additional unused 288 million tCO2e certificates could have generated another €1.37 billion at 2012 prices. Among participants, firms have saved on average €799,000 while the median is only €31,200.[25]

4.3 Evidence for transaction costs

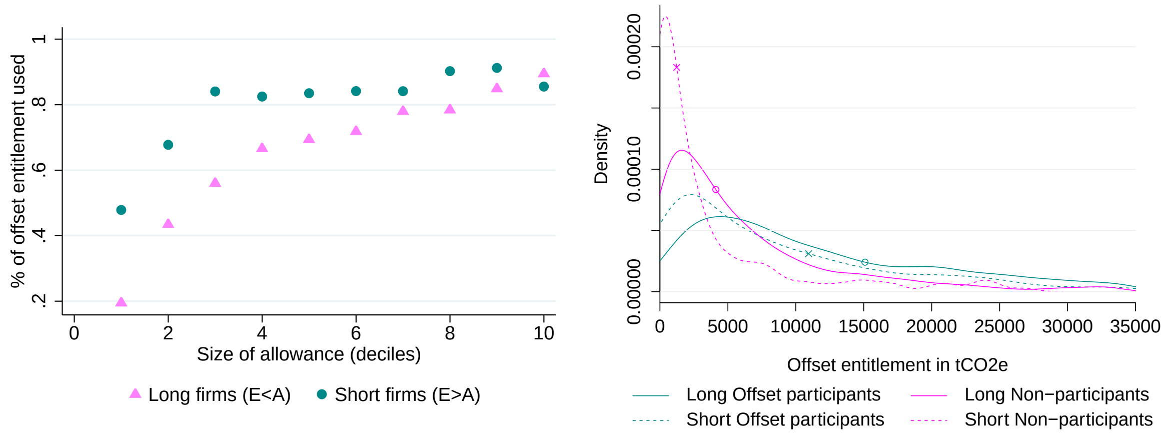
As mentioned before, many firms did not use their offset entitlements. Given the large supply of offset certificates and their relatively low price, this is surprising. One potential explanation for firms not participating in the market is that their expected pay-off was not high enough to cover transaction costs of information procurement, such as the cost of hiring additional personnel or devoting existing resources to compliance optimization.

The stylized facts supporting this idea are (a) a largely binary behavior between using either the maximum allowed or no offsets at all; (b) the non-neutrality of EUA allocation status for participating in the offset market; and (c) an increasing likelihood of participating in the offset market as offset entitlement increases.

Firms have mostly followed an "all-or-nothing" strategy in their offset usage, suggesting the presence of fixed participation cost: Figure 5 shows the used offsets as a percentage of the total offset entitlement. One can see two frequency spikes: over half of the firms use *all* their offset entitlements and almost a quarter of the firms use *none*. Finally the last quarter of firms use some but not all of their offset entitlement. While per-unit costs would lead to a marginal trade-off and intermediate usage rates, a fixed cost incurred for market entry could explain such a binary behavior. It is interesting to note that many multi-plant firms with intermediary usage are composed of plants that expose an all-or-nothing behavior: it seems likely that this results from coordination problems within firms.

The main consequence of transaction costs is that they make initial allocation non neutral (Stavins, 1995). With fixed costs, firms with large credit entitlements should participate more as entry costs become small compared to the potential gain. Moreover, short firms are legally bound to trade so that

[25]These numbers take prices as given, so they cannot be interpreted as the general-equilibrium savings from offset usage: as seen in Section 2.2, the counterfactual EUA price in absence of offset credits would have been higher than the observed prices. The *de facto* achieved savings from offset usage are probably higher than my esstimates used in Table 2. Stephan et al. (2014) estimate demand elasticity as being relatively high, such that actual firms' savings may be as high as €20 billion, as offset availability decreased the overall stringency of the cap. Moreover, it does not include the incurred transaction costs.



(a) Offset usage by allocation and according to size deciles of offset entitlement, or potential profit

(b) Distribution of offset entitlement in the different groups of firms

Figure 6: Relationship between offset participation, offset entitlement and allocation status (source: EUTL and own computations)[26]

they should consider general trading cost as sunk, whereas the offset-specific cost applies to both long and short firms. Figure 6a shows the interaction between the size and the allocation status: at lower size deciles, firms use offsets relatively rarely, with a large difference between long and short firms. As size increases, firms become more likely to use more offsets, while at the same time the difference between long and short firms becomes less marked. At the tenth size decile, virtually all firms participate and there is no significant difference between long and short firms' behavior.

Assuming that firms take rational decisions, plants that do not participate must estimate their participation cost to be *higher* than their potential profit, such that the mean offset entitlement multiplied by the mean price spread should give us a *lower bound* of the magnitude of these transaction costs (similar to the reasoning in Attanasio and Paiella, 2011). At the same time, the opposite is true for participating firms. These two distributions largely overlap, but Figure 6b shows that the means and medians are strongly different. In general non-participating firms tend to be smaller, with half of firms below 3,600 tCO2e of offset entitlements (while the median is 16,600 tCO2e for participating firms). Nevertheless, the distributions both stretch out until above 50,000 tCO2e, showing that the separation is not clear cut. The largest non-participant firm has 262,000 tCO2e entitlement, and the 9 percentiles of the potential profit distribution above this value *all* participate. Among participating firms, the size distribution of long and short firms is similar. On the opposite, small short firms are overrepresented in the non-participating group. This gives us an order of magnitude of avoided transaction costs.

Figure 6b shows that the size distribution of firms' offset entitlements is highly unequal, and similar inequality is true for emissions, number of plants and grandfathered allocations. The empirical methods used need to be chosen such that they are robust to these rare and extremely large outlier firms.

[26]Density estimation using Gaussian kernel from density() in R, with smoothing bandwidths calculated by Silverman's rule of thumb; for readability, the graph is cut at 50 ktCO2e, although both densities continue beyond. Crosses and circles indicate median values.

4.4 Econometric methodology

The model gives us an indication about the link between firm behavior (using any offset credits or not) and the magnitudes of the unknown entry costs T^o and T^e to be estimated, relative to the known quantities A_i, E_i and $\Delta_p K_i$. We want to measure the unobserved (latent) fixed transaction cost TC_i^*, while observing only the binary outcome $\mathbb{1}_i^o$ equal to 1 if TC_i is smaller than $\Delta_p K_i$:[27]

$$\begin{aligned} \mathbb{1}_i^o &= \mathbb{1}\{\Delta_p K_i > TC_i^*\} \\ &= \mathbb{1}\{\underbrace{\Delta_p K_i}_{\text{potential profit}} > \underbrace{T^o + T^e \mathbb{1}_i^{long} + \epsilon_i}_{\text{entry cost}}\} \end{aligned} \tag{15}$$

In this binary choice setup, $\Delta_p K_i$ is the firm-specific cut-off value relevant for the decision to participate. Other than in most binary choice settings, e.g. standard probit, a firm-specific cut-off allows us to identify an intercept as it fixes a scale for the two estimated parameters T^o and T^e in terms of units of $\Delta_p K_i$ (i.e. Euros).[28] This method to use preference revelation is similar to the methodology of contingent valuation, often used to analyze "willingness-to-pay" (WTP). Here, rather than estimating WTP, I interpret the foregone profits as "unwillingness-to-benefit" to identify transaction costs.[29]

If the error term was assumed to be *iid* following a normal distribution, equation (15) would describe a probit model in which coefficients are normalized such that the coefficient of the potential profit equals 1. The other coefficients then measure transaction costs in Euros. This relates to the contingent valuation literature, where willingness-to-pay is estimated by normalizing the utility of income to 1.[30] However, the stylized facts presented in Section 4 strongly suggest that this homoskedastic normality assumption does not hold. If the distribution of transaction costs is skewed, an estimation of the mean cost is not the most representative summary statistic as it might be driven by large outliers.

Following empirical work from Kordas (2006) and Belluzzo Jr (2004), I estimate a range of binary quantile regressions to analyze the whole conditional distribution of transaction costs rather than only the conditional mean. This semi-parametric method is more robust to non-symmetric error distributions and outliers. For all quantiles $\tau \in [0, 1]$, I define the conditional quantile $Q_{TC^*}(\tau)$ as the τ^{th} quantile of the transaction cost distribution F_{TC^*}:

$$Q_{TC^*}(\tau|\mathbb{1}_i^{long}) := F_{TC^*}^{-1}(\tau) = T_\tau^o + T_\tau^e \mathbb{1}_i^{long} \tag{16}$$

These quantiles are identified using the observed offset-market participation $\mathbb{1}_i^o$ and the monotone transformation of equation (15). Then $Q_{\mathbb{1}_i^o}(\tau)$ may be written as:

$$Q_{\mathbb{1}_i^o}(\tau|\mathbb{1}_i^{long}, \Delta_p K_i) = \mathbb{1}\{\Delta_p K_i \geq T_\tau^o + T_\tau^e \mathbb{1}_i^{long}\} \tag{17}$$

The probit regression draws its identification from the conditional mean assumption $E(\epsilon_i|x) = 0$

[27] We observe a transformation of the latent variable by an indicator function, which is a monotone transformation. See Koenker and Hallock (2001) on the equivariance of quantile estimates to monotone transformations.

[28] K_i is measured in tCO2e of offset entitlement and Δ_p is the average price spread measured in €/tCO2e.

[29] Note that unlike most of the contingent valuation literature this study does not use survey methods, in other words, I am working with revealed preferences rather than stated preferences. I therefore avoid much of the standard critique of contingent valuation methodology, which questions the validity of survey answers, cf. Diamond and Hausman (1994)

[30] The standard normalization of a probit sets the standard deviation σ to 1; in contrast, the standard deviation is a free parameter here.

and the normality assumption, while the following methodology estimates the median and thus is identified over the assumption that the conditional median error is zero. The earliest estimator using this semi-parametric assumption is the maximum score estimator by Manski (1975). At the median (with $\tau = .5$) this estimator maximizes the number of "correct predictions" using an indicator function:

$$\max_{T^o_\tau, T^e_\tau} S_{n\tau}(T^o_\tau, T^e_\tau; \Delta_p K_i) = n^{-1} \sum_{i=1}^{n} [\mathbb{1}^o_i - (1-\tau)] \mathbb{1}\{\Delta_p K_i - T^o_\tau - T^e_\tau \mathbb{1}^{long}_i \geq 0\} \tag{18}$$

Similarly to the median, we can estimate other conditional quantiles. While this estimator is relatively intuitive, it is not continuous, which makes it difficult to optimize and determine standard errors. To solve this problem, Horowitz (1992) formulates a smoothed maximum score estimator using a kernel function to get a continuous function of the estimated parameters, which is extended to quantiles other than the median by Kordas (2006). The smoothed binary quantile estimator at quantile $\tau \in (0,1)$ is the solution to the following problem:

$$\max_{T^o_\tau, T^e_\tau} S^*_{n\tau}(T^o_\tau, T^e_\tau; h_n, \Delta_p K_i) = n^{-1} \sum_{i=1}^{n} [\mathbb{1}^o_i - (1-\tau)] \Phi\left((\Delta_p K_i - T^o_\tau - T^e_\tau \mathbb{1}^{long}_i)/h_n \right) \tag{19}$$

where $\Phi(\cdot)$ is a continuous, differentiable kernel function and h_n an appropriate bandwidth that tends to zero as sample size increases.

The estimation of this model involves the optimization over a complex function, in particular when using the discrete version of equation (18). I use R to implement Kordas' S-Plus/Fortran code to perform simulated annealing following the algorithm of Goffe et al. (1994). Simulated annealing has the advantage of being more robust to starting values, local optima and discrete parts of the objective function; although computationally more demanding, the full code including bootstrapping runs in less than six hours . With a large sample such as the one used in this study, results of Manski's discrete quantile maximum estimator and Horowitz' smoothed estimator turn out to be virtually identical. Standard errors for both estimators are calculated by bootstrap methods.

5 Estimation results

The results show that transaction costs are roughly €100,000 on average, which results from a skewed distribution: many firms face small transaction costs, while a few firms have very high costs. In particular, the offset-specific cost is much smaller for most firms. This section illustrates how quantile regressions can add valuable information if the underlying distribution is asymmetric.

The binary quantile regression estimates the distribution of transaction costs from which each firm draws its realized transaction cost. Note that this is different from transaction costs for different sizes of firms. As this distribution is not assumed to follow a known functional form, it is described here by estimating 19 quantiles, from the 5th to the 95th percentile in steps of 5 percentage points. For better readability, Table 3 shows only selected quantiles, while Figure 7 shows the full estimation for all quantiles (19 separate estimations).

The transaction cost components are measured in units of potential profit, i.e. in euros. The median offset-specific cost T^o is estimated around €905, which means that a short firm with enough offset entitlement to generate €905 of offset revenue has a 50% chance of participating. While transaction

τ	All firms		Manufacturing		Electricity	
	$\hat{T}^o$	$\hat{T}^e$	$\hat{T}^o$	$\hat{T}^e$	$\hat{T}^o$	$\hat{T}^e$
	offset-sp.	general	offset-sp.	general	offset-sp.	general
0.05	35.0***	1.0	950.6***	12.5	35.6***	-13.2
	[25; 152]	[-94; 587]	[345; 1,308]	[-89; 2,335]	[21; 143]	[-87; 1,140]
0.1	35.0***	1.0	1,013.8***	936.0	32.7***	-.7
	[30; 344]	[-96; 1,824]	[354; 1,359]	[-64; 2,919]	[25; 284]	[-93; 1,373]
0.25	472.9***	2,817.5***	965.0***	2,732.8***	338.5***	4,198.3***
	[35; 587]	[1,444; 4,675]	[330; 1,378]	[797; 4,429]	[32; 906]	[718; 7,867]
0.5	904.7***	7,769.5***	1,045.3***	5,417.8***	917.0***	7,695.8***
	[378; 2,753]	[3,976; 10,616]	[340; 1,538]	[4,015; 10,696]	[393; 5,169]	[2,880; 15,417]
0.75	9,352.6***	17,876.2***	1,295.6***	21,376.0***	12,587.2***	15,291.6**
	[2,746; 12,741]	[9,995; 30,478]	[393; 11,331]	[11,276; 36,002]	[3,970; 26,390]	[1,466; 29,466]
0.9	28,392.9***	57,135.0**	21,426.0***	63,250.2***	88,307.2***	108,950.3*
	[17,596; 99,858]	[1,712; 165,116]	[11,018; 52,336]	[32,879;132,068]	[29,228;170,252]	[1,223; 141,695]
0.95	201,919.4***	7,184.6***	301,294.8***	13,588.2*	165,532.4***	31,900.4*
	[79,334;304,069]	[264; 476,038]	[23,545;309,215]	[102; 486,145]	[65,021;236,666]	[5,274; 388,442]
Mean	83,675	21,519	123,133	64,269	65,322	62,542
Probit	109,557***	44,302***	173,656***	98,911***	48,632**	4,059
N	4,578		2,938		1,640	

Function optimized by simulated annealing, significance and point-wise 95% confidence intervals are determined by bootstrap (500 replications). Columns 1 and 2 show the result of the binary quantile regression, dependent variable is the offset participation dummy, regressors are offset entitlement (normalized to one), allocation dummy and a constant. Columns 3 to 6 show the result of the same regression with additional dummies for sector affiliation (and their interaction with the allocation dummy). Manufacturing includes cement, pulp and paper, glass, ceramics, metals, oil refining and "other".

Table 3: Estimates from the binary quantile estimator

costs are relatively low around €500 for the lower quarter of the transaction cost distribution, their values are high at the upper end with €201,919 for the highest quantile ($\tau = .95$). The distribution for T^e indicates that long firms (with generous initial allocations) are much more reluctant to participate. At the median, their behavior is consistent with an *additional* cost equivalent to €7,770. This goes up to the higher quantile estimates around €41,900 for $\tau = 0.95$. A long firm thus needs €7,770+ €905= €8,675 to have a 50% participation probability.

The quantile analysis reveals that the transaction cost distribution spans a large range and is strongly skewed : while the difference between the median quantile and lower quantiles is small, there are large outliers driving the estimates of the highest quantiles. Consequently, the means (lower part of Table 3)[31] can be misleading about the transaction cost distribution. Of a similar order of magnitude, the probit estimates (of the conditional mean) are also much higher than the median.[32] Figure 7 plots probit estimates with a cross and adds the distribution of the normal error to represent the distribution implied by probit assumptions.[33] It shows that in spite of the similar means, quantile and probit estimates are significantly different for most quantiles and yield very different views on the transaction cost distribution.

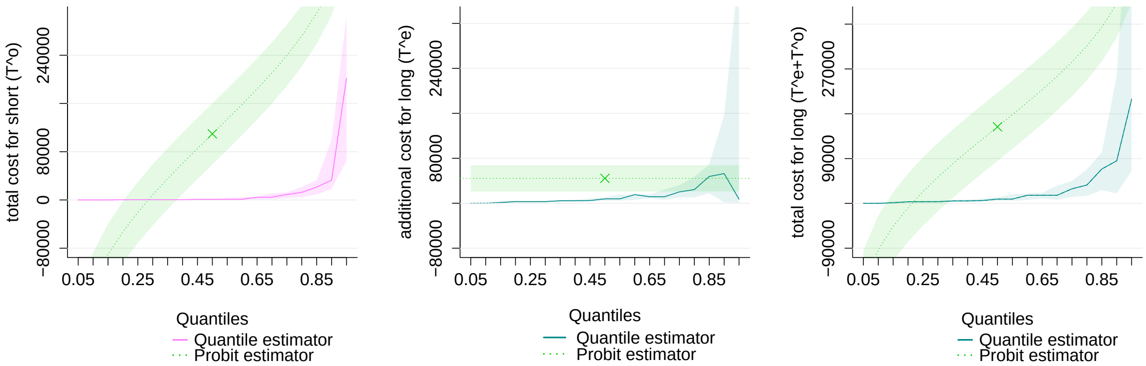
Note that for virtually all quantiles, the impact of allocation status is stronger than the offset-specific transaction cost: the bulk of transaction costs stems from the general cost component T^e.

[31]Means from the quantile regression are computed with the following steps: (a) estimate quantile parameters in 5% steps from the 5th percentile to the 95th; (b) predict participation probability depending on firm characteristics (see Appendix D); (c) impute transaction cost from τ equal to predicted probability; and (d) take average across all observed firms.

[32]More detail on these parametric estimations can be found in the Appendix on page 29.

[33]Due to the renormalization, the error term does not follow a standard normal distribution, instead having a larger standard deviation.

[34]Quantile estimates for all 5th percentiles from 5% to 95%. The dotted green line is the mean estimate from probit, the shaded bands represent the point-wise 95% confidence intervals.

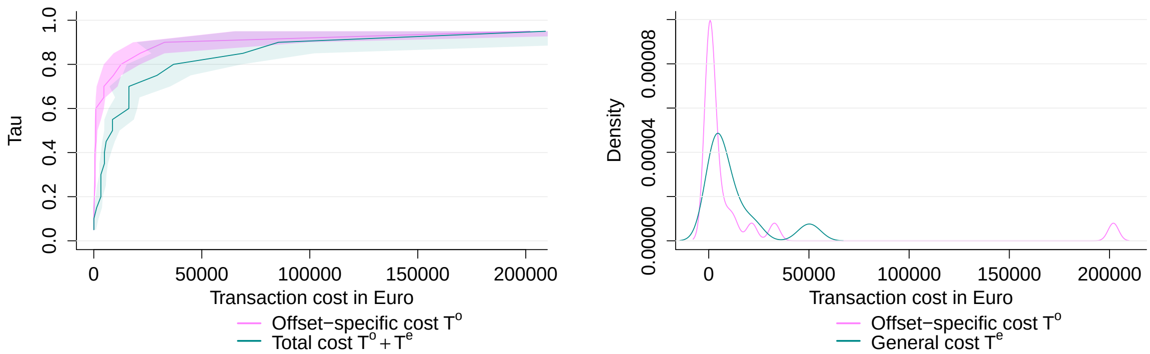


(a) Offset-specific cost (b) General trading cost (c) Sum of both costs

Figure 7: Estimated transaction cost (in €) - quantile plot[34]

This means that it is not the offset trading *per se*, but rather the cost of emissions trading in general that stopped firms from using their offset entitlement. However this finding is completely hidden if we look only at the means, both from probit and from quantile regression (Table 3), which show that transaction cost for offset are *on average* larger than the ones for general trading. There are some large outliers in the distribution of T^o.

A straightforward way to make these results more intuitive is to switch the axis of the standard quantile plot Figure 7 in order to get the estimated cumulated density function of firm's transaction costs as shown in Figure 8a. From there, one can infer a probability density function from this CDF by using standard kernel density methods as in Figure 8b. Again, these figures show how the high mean of T^o is driven by some large outliers: the tail of the probability density function of the offset-specific transaction cost shows a bump that is driven by the only four non-participating firms with potential profits above €200,000. The mean may be considered a misleading statistic in such a case.



(a) Cumulative density function (b) Probability density function

Figure 8: Estimated transaction costs[35]

Figure 9 compares the estimated probability of participating in the offset market from the probit and quantile model to the observed frequencies at different entitlement magnitudes. Particularly for

[35]Pdf in Fig. 8b estimated from Fig. 8a using kernel density in R.

smaller emitters, the quantile method predicts participation probability much better than the probit. Analoguously, the fit of the quantile estimation is strong if evaluated with the method outlined by Kordas (2006), i.e. checking that predicted and observed probabilities roughly coincide (cf. Appendix on page 31). However, the better fit does not come as a surprise: the quantile model fits 38 free parameters, while the probit only fits three free parameters.

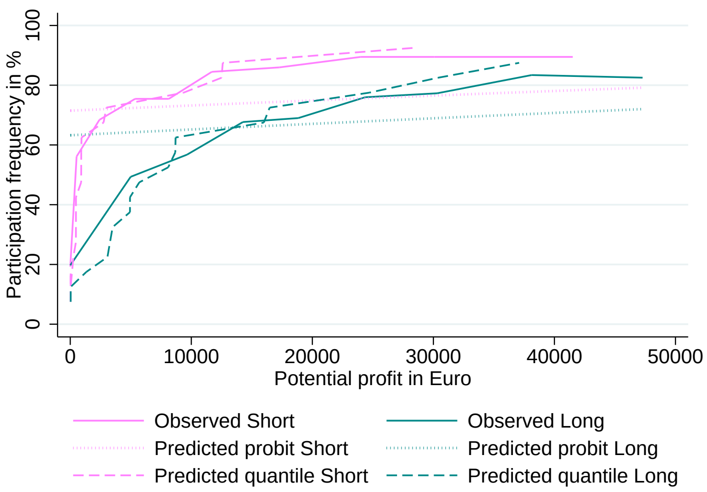


Figure 9: Observed frequencies and predicted probabilities of quantile method and probit (cut at 40,000 tCO2e for better readability)

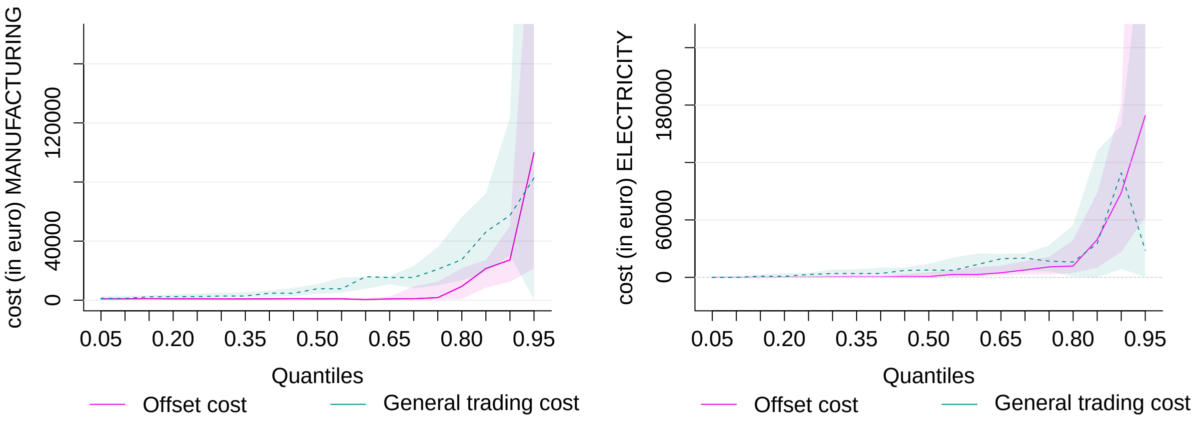
5.1 Sector-specific results

While a full sector-specific analysis is not possible with a data set of this size, the right-hand side of Table 3 shows the result if I broadly separate manufacturing and electricity-generating firms. Electricity and heat generation account for one third of all firms, and half of total emissions.[36] Electricity firms are known to have active and sophisticated compliance and trading behavior, likely because of the experience from electricity trading (Heindl, 2012).

Results (Table 3 and Figure 10) show that this sector separation explains some of the observed transaction cost heterogeneity: while costs are similar around the median for manufacturing and electricity firms, I do not find any large outlier in the electricity sector, such that this sector's means are considerably lower compared to manufacturing. The high result at the 95th percentile of the pooled estimation is driven only by a handful of manufacturing firms.

The estimates for several quantiles of the general cost T^e are not significant for electricity and heat generation firms. Moreover the probit estimate is not significant. As virtually all large electricity firms trade emission certificates, it is difficult to precisely identify this general component. For manufacturing however, estimates are very similar to the ones for the general case: means are much higher than medians, offset-specific cost are less relevant than general cost for most of the distribution and the means nevertheless are higher for T^o.

[36]Readers familiar with the EU ETS might find these numbers low. Note that the electricity market is characterized by large firms owning many plants, such that their share in the overall *number* of firms appears small. Moreover, I use NACE 2 codes of the firms' *main* activity rather than the activity code that led the firm to be regulated under the EU ETS; e.g. hospitals (main activity) fall under the EU ETS regulation, because they typically run large fossil-fuel power generators for back-up power and heating.



(a) Manufacturing

(b) Electricity and heat generation

Figure 10: Sector-specific quantile estimation results (in €)

6 Conclusion

Within their obligations from the EU ETS, firms had the opportunity to reduce expenses by using their right to substitute European certificates with international offset certificates. *A priori* it is always profitable to use the cheaper offset certificates. However, many firms do not make full use of their offset entitlement. After briefly explaining the aggregate mechanics of offsets in the EU ETS, this study explains the theoretical impact of fixed transaction costs on offset usage and estimates the distribution of fixed transaction costs necessary to rationalize firms' participation in the offset market.

Prior work has used survey data to show that compliance with the EU ETS generates managerial costs. To the best of my knowledge, this is the first study establishing a framework to assess these transaction costs empirically through the use of administrative data. These entry costs are estimated to be at the median €7,770 (average €21,519) for general participation in the certificate market (be it EUA or offset certificates) plus €905 (average €83,675) for offset participation. Overall, the empirical results underline that the behavior on the offset market is significantly impacted by initial allocation: for most firms transaction costs are largely due to general participation in emissions trading, rather than the offset market specific setup costs. However, this average hides a large heterogeneity that is best captured by a quantile estimation that suggests that these means are driven by some large outliers. As a consequence, this study illustrates the advantage of using binary quantile methods rather than usual parametric approaches that focus on the mean.

Environmental policy aims at reducing ecological harm at minimum cost to society. Most academic and policy-related work accounts for direct compliance or abatement cost of the EU ETS. However – just like any regulation – the EU ETS causes administrative and management-related transaction costs. My estimates suggest that these costs are relevant in practice: firms significantly deviate from the least-cost scenario. Indeed, designing policy is "an empirical matter" as Montero (1998) puts it. Usually, optimal regulation aims at giving the optimal incentive structure, while this study argues that regulatory complexity also creates costs. As the objective of a regulation becomes more complicated, there appears to be a trade-off between incentive perfection and a need to keep complexity for the regulated firms at bay – incentives only work as intended if they are understood and implemented at low cost. In this perspective, this paper aims at contributing to the practical debate about the shape of environmental policy. Empirical evidence for transaction costs calls for more simple permit designs, rather than more sophisticated (but complicated) policy designs. The problem is even more stringent if the costs impact firms differently, such as the fixed costs estimated in this study, where only large firms benefit from the cost reduction of offset certificates. On this last point, some action has been taken on national level with programs excluding small emitters from the scheme, e.g. the UK "Small emitter and hospital opt-out" program.

My residual definition of transaction costs addresses only part of the actually arising transaction costs: all other costs that are not choice-dependent, i.e. cannot be influenced by firm behavior, cannot be captured with my methodology, e.g. costs due to monitoring and reporting and registry fees.[37] In a way, my estimates are thus the lower bound of the costs that should be included in the policy discussion. More importantly, these transaction costs are not synonymous with overall efficiency loss: while effort spent in information gathering is certainly not welfare-improving, a real welfare effect analysis would need to look at the bigger picture of the general equilibrium. It would be interesting to estimate the impact of offset certificates on EUA prices, as well as to further dig into the price distortions (both on EUAs and offsets) caused by transaction costs.

The estimated transaction cost is a "black box" measuring *all* the frictions stopping firms from investing in offsets. It remains to be analyzed exactly what these costs include and how they could consequently be reduced to implement a less distortionary policy. In fact, this study cannot differentiate between financial costs and more "behavioral" reasons, such as inattention, salience, risk aversion, misperceptions, etc. Importantly, firms' aversion to use offsets could also be due to reputation considerations, as offsets have received bad press in most countries.[38] However, we are talking about the behavior of firms, such that psychological factors should play less a role than they do for consumer decisions. Finally, the claim that frictions are considerable remains valid even if they stem from behavioral factors rather than purely efficiency-driven cost considerations.

[37] Registry fees in Phase II ranged from €100 for the period to €15,000 per year, depending on the country and (for some countries) emission size, cf. EUTL website.

[38] The VAT tax fraud as well as cyber-attacks on registries in 2010 and 2011 touched mostly European certificates and should not impact this study's results. However, there was considerable public discussion about the actual *additionality* of offsets. Note that while this might explain firms' unwillingness to use offsets in general, it seems unlikely that it affects the identification of the general transaction cost component.

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A National offset entitlement rules

	Annual Cap Ph.II (MMt CO2e)	Offset limit (%)	Annual offset limit (MMt CO2e)	Banking/ Borrowing	Industry	Energy	Other sector differentiation	Included in this study
Austria	30.7	10	3.1	Yes/yes				
Belgium	58.5	8.4	4.9	-	Flanders 24% Walloon 4%	Flanders 7% Walloon 8%		
Bulgaria	42.3	12.6	5.3	Yes/yes				
Cyprus	5.48	10	0.5	Yes/yes				
Czech Rep.	86.8	10	8.7	Yes/yes				
Denmark	24.5	17	4.2	Yes/yes	6.50%	28.70%		
Estonia	12.72	10	1.3	No/no		(started only in 2011)		No
Finland	37.6	10	3.8	Yes/Yes	8 / 8.5%	8.5 /9.5 /23.9%		
France	132.8	13.5	17.9	Yes/Yes				
Germany	453.1	22	99.7	Yes/Yes				
Greece	69.1	9	6.2	Yes/Yes				
Hungary	26.9	10	2.7	-				
Ireland	22.3	10	2.2	Yes/Yes	5%	11%	Cement 11%	
Italy	195.8	15	29.4	Yes/no	7.2%	Electricity 19.3%	"Other" combustion 7.2%	
					Ferrous metal 16.7%	Refineries 13.2%		
Latvia	3.43	10	0.3	Yes/Yes				
Lithuania	8.8	20	1.8	No/no				No
Luxembourg	2.5	10	0.3	Yes/Yes				
Malta	2.1	10	0.2	Yes/Yes				No
Netherlands	85.8	10	8.6	Yes/Yes				
Norway		13		Yes/No		13% of actual emissions (rather than allocation)		No
Poland	208.5	10	20.9	Yes/No				
Portugal	34.8	10	3.5	Yes/Yes				
Romania	75.9	10	7.6	Yes/Yes				
Slovakia	30.9	7	2.2	Yes/Yes				
Slovenia	8.3	15.8	1.3	Yes/Yes				
Spain	152.3	20.6	31.4	Yes/No	7.90%	42%		
Sweden	22.8	10	2.3	Yes/Yes				
UK	246.2	8	19.7	Yes/No	8%	9.30%		

Table 4: Offset limits collected from National Allocation Plans by Elsworth et al. (2012)

B Are emissions constrained by transaction costs?

In Section 3.2, I claim that firms do not strategically constrain (or "manipulate") their emissions to be just below allocation level, even though firms face a cost curve that jumps when emissions increase beyond this level (Figure 3a). This assumption is important, as I use the fact that *short* firms, with emissions above allocations, are constrained to trade while *long* firms can choose whether to incur trading entry costs. However, this methodology is flawed if transaction costs lead firms to manipulate their allocation status. This section argues, that this case is unlikely to be relevant in practice. Firms choose their production and emissions given production cost and certificate prices; the additional transaction cost is likely to be smaller than the cost of adjusting emissions and production. Empirically, there is no significant discontinuity around the allocation status threshold.

First, note that the firm faces the same marginal cost p^e for emissions both below and above the jump of Figure 3a and 3b, such that marginal abatement cost does not play a role. However, overall compliance cost increases; the firm thus compares two situations: one where emissions are reduced to allocation level A_i, such that optimal production is $Y^*(A_i)$ and entry costs are *not* incurred, and another situation where $E_i^* > A_i$ is chosen such that marginal abatement cost equals p^e and entry cost is incurred. The firm reduces its emissions to A_i if the change in profit Δ_π resulting from this reduction is positive:

$$\begin{aligned}
\Delta_\pi &= \pi(Y^*(A_i), A_i) - \pi(Y^*(E_i^*), E_i^*) && (20)\\
&= (Y^*(A_i) - Y^*(E_i^*))p - C(Y^*(A_i), A_i) + C(Y^*(E_i^*), E_i^*) - T^*(A_i) + T^*(E_i^*) && (21)\\
&= p(Y^*(E_i^*) - Y^*(A_i)) - C(Y^*(E_i^*), E_i^*) + C(Y^*(A_i), A_i) - p^e(E^* - A) - T^e - min\{T^o - \Delta_p K_i, 0\} && (22)
\end{aligned}$$

By assumption, we are looking here at cases where optimal emissions $E_i^* > A_i$ and thus $Y^*(E_i^*) > Y^*(A_i)$; by definition of the optimal emission level E_i^*, Δ_π would always be negative without the transaction cost terms of equation (21) (or, to be more precise, the left-hand side of equation (??)). As seen on Figure 3, the change in incurred transaction cost is either T^e, as on Figure 3a, or $T^e + T^o - \Delta_p K$, see Figure 3b.

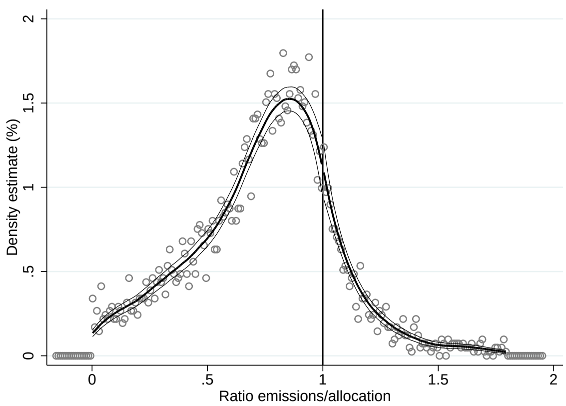
Anecdotal and survey evidence (Loeschel et al., 2010, 2011) suggests that firms do not have precise and continuous control over their emissions, or rather that there are considerable transaction costs to obtain such control. Only large companies regularly track their emissions throughout the year. The trading scheme's incentives to reduce emissions do not work on a short-term "accurate to the tonne" level, but rather on a long-term technology-inducing level.

Most technologies are such that in the short term the actual technological margin to reduce emissions without a complete corresponding reduction of output is limited; reducing emissions by a certain share is thus equivalent to reducing production by the same share. After all, emissions are just one production cost factor among many others and the short-run flexibility of the cost function is usually low (meaning that emission reductions are to a large extent matched by reductions in the produced outcome). Emission reductions are mostly accomplished in the long term through technical change, whereas this study is looking at short term behavior. Even for a small difference between E_i^* and A_i it is likely that Δ_π is strictly negative.

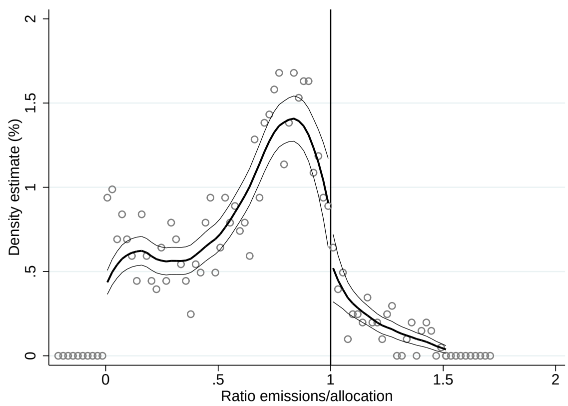
A priori this case thus seems not so relevant in practice. However, it cannot be verified fully, as information on prices p, quantities Y and production costs are not available, neither cost function $C(Y, E)$ nor the profit change Δ_π can be estimated. Instead, one way of gathering (descriptive) evidence on this point comes from checking whether we observe any crowding or "bunching" of emission levels just below $E = A$. If many firms were manipulating their allocation status, the distribution of this ratio would be somewhat discontinuous around $E/A = 1$. Figure 11 implements McCrary's test for continuity (McCrary, 2008). The estimated densities on the left and on the right of the cut-off where $A = E$ seem smooth on Figure 11a: at a discontinuity magnitude of .0116 (in logs) and a standard error of .1133, we cannot reject the hypothesis that there is no bunching around the threshold, or put differently, that the ratio's density function is continuous around this point. Moreover, restraining emissions to become *long* should be particularly relevant for firms that do not use offset certificates, as they incur transaction costs anyways. Therefore Figure 11b shows the McCrary test only for the firms that do not participate in the offset market: while the discontinuity appears somewhat clearer here, there is still no significant bunching at $E = A$ (discontinuity estimate at -.3910 with standard error of .2766).

A notable exception might be emission savings by electricity generating plants, as some firms have scope for fuel-switching across different plants and emission costs are a more important cost factor in this industry. However, the McCrary test also does not show a significant jump if we are looking at electricity firms only.

While theoretically not fully sound, the assumption of exogenous allocation status thus seems empirically valid and in line with anecdotal evidence.



(a) All firms
– discontinuity estimate (in log) .0117, se .1133



(b) Only firms which do not submit offsets
– discontinuity estimate (in log) -.3910, se .2766

Figure 11: McCrary's test for continuity of the running variable (ratio emissions/allocations) [39]

[39]Estimated using Stata DCdensity command by Brian Kovak.

C Parametric estimation results

A standard way to estimate the parameters of equation (15) is to assume a standard normally distributed error term ϵ_i. The model then becomes similar to a standard probit model: $\Delta_p K_i$ is included as a regressor and coefficients are then normalized such that the coefficient on K_i equals -1. The estimation equation reads:

$$\mathbb{1}_i^o = \mathbb{1}\left\{\beta_0 + \beta_1 \mathbb{1}_i^{long} + \beta_2 \Delta_p K_i + \epsilon_i > 0\right\} \tag{23}$$

Standard statistical packages normalize the standard deviation σ to 1. A re-normalization then yields the parameters of interest:[40]

$$\hat{T^o} = -\frac{\hat{\beta}_0}{\hat{\beta}_2}; \qquad \hat{T^e} = -\frac{\hat{\beta}_1}{\hat{\beta}_2}; \qquad \hat{\sigma} = \frac{1}{\hat{\beta}_2} \tag{24}$$

The stylized facts presented in Section 4 strongly suggest that this homoskedastic normality assumption does not hold. As shown before, the distribution of offset entitlements is highly skewed with some firms more than 500 times bigger than the (relatively low) median. Moreover, some firms with high K_i still do not exploit their offset entitlement, such that the distribution of ϵ_i from the transaction cost equation (15) is likely to have some large outliers. The (conditional) mean is a statistic much more sensitive to outliers than the (conditional) median; differently put, the normal distribution assumption has light tails which consequently give large weight to outliers.

A slightly more flexible functional form relaxing the homoskedasticity assumption, would be the mixed probit: error terms are still assumed to have a normal distribution, but the variance scales with the size (here K_i) of the firm. In such a location-scale model, the variance of each ϵ_i depends on some scaling variable and a parameter γ (to be estimated):

$$\epsilon_i \sim \mathcal{N}(0, \sigma_i^2), \text{ where } \sigma_i = \exp(K_i \gamma) \tag{25}$$

This section shows the results for both assumptions, while claiming that they are not an accurate description of the data. The results the probit estimation in both the homoskedastic and (linearly) heteroskedastic versions are shown in Table 5.[41] The costs indicated are measured in euros, as they are normalized by the cut-off value's $\Delta_p K_i$ coefficient. The estimate for T^o, the transaction cost for offset usage, is larger than the estimate for T^e, while both are significant. When I include the sectors, the estimates for transaction costs in the manufacturing sector are much higher than in the electricity and heat generation sector. In particular, general trading cost T^e seems not relevant for electricity and heat generating firms.

[40] Standard errors for the re-arranged parameters are computed using Stata's nlcom command, based on the delta method.
[41] Estimated using Stata oglm command by Williams (2010).

	Probit	Heterosk. probit	Probit with sectors	Heterosk. probit with sectors
$\hat{T}^o$ (intercept)	109557***	102660***		
	(4.24)	(4.36)		
$\hat{T}^e$ ($\mathbb{1}^{long}$)	44302***	42798***		
	(3.70)	(3.79)		
$\hat{T}^o$ Manufacturing			171436***	161416***
			(4.48)	(4.63)
$\hat{T}^e$ Manufacturing			96475***	92138***
			(4.42)	(4.53)
$\hat{T}^o$ Electricity			48383**	278077***
			(2.58)	(4.54)
$\hat{T}^e$ Electricity			4169	5065
			(0.25)	(0.32)
σ	192950***	182835***	192434***	182472***
	(5.77)	(6.04)	(5.82)	(6.09)
γ		6.96e-08***		6.95e-08***
		(18.15)		(18.24)
R2	.1274	.128	.1372	.1378
Completely determined	371	.	369	.
N	4578	4578	4578	4578

t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Parametric mean estimates for transaction costs

D Quantile regression fit

Kordas (2006) suggests verifying the fit of the quantile regressions by predicting probability intervals for each observation and verifying that each interval group has a participation rate close to the predicted probability. Predicting probabilities from the binary quantile regression is simple: one needs to find the smallest quantile $\hat{\tau}_i$ such that the profit-net-of-transaction costs is positive:

$$\hat{\tau}_i = argmin\{\tau : \Delta_p K_i - T^o - \mathbb{1}_i^{long} T^e \geq 0\} \tag{26}$$

Then this gives us an interval for the conditional participation probability:

$$\hat{P}_i \in [1 - \hat{\tau}_i, 1 - \hat{\tau}_{i,-1}] \tag{27}$$

where $\hat{\tau}_{i,-1}$ is the quantile immediately preceding $\hat{\tau}_i$.

For the data used in this study this gives the predicted and observed probabilities displayed in Table 6. Except for the lowest quantile, the models seem to fit the data reasonably well. On the opposite, the probit model predicts for *all* firms a participation probability above 50%: one could says that *all* non-participating firms are unpredicted outliers (false-negatives) with the probit model.

Predicted probability	<15%	[15-25%]	[25-35%]	[35-45%]	[45-55%]	[55-65%]	[65-75%]	[75-85%]	>85%
Number of observations	85	130	65	49	153	414	613	971	2098
Observed frequency	11%	17%	32%	43%	46%	58%	72%	81%	94%

Table 6: Specification test of binary regression quantile models (predicted and observed probabilities)