

Naegele, Helene

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Offset Credits in the EU Emissions Trading System : A Firm-Level Evaluation of Transaction Costs

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Offset Credits in the EU Emissions Trading System : A Firm-Level Evaluation of Transaction Costs

February 27, 2015

[including PRELIMINARY results]

Abstract

International offset certificates have systematically traded at a lower price than European Union Allowances (EUAs), although they are perfect substitutes. Firms therefore had a strong incentive to use the cheaper certificates up to the maximum quantity fixed by the regulator. This study highlights that a considerable number of firms did not use their offset credit entitlement and by doing so seemingly forwent profits, which supports the idea that significant transaction costs exist in carbon permit trade. While most of the literature on emission trading evaluates the efficiency of regulation in a frictionless world, firms in reality face managerial costs of compliance with regulation. This study examines the use of international offset credits within the EU Emissions Trading System (EU ETS) for carbon dioxide, in order to assess the relevance of such managerial and information-related transaction costs. This study further establishes a model of firm decision under fixed entry costs and estimates the size of transaction costs rationalizing firm behavior using both standard parametric and semi-parametric binary quantile regression methods. These costs appear to be sizable and make active optimization of compliance unprofitable for many small emitters. It appears that a large portion of these transaction costs stems from participation in the EU ETS in general, rather than additional participation in the offset trade.

JEL : Q58, D23, H23

Keywords : Environmental policy, transaction costs, EU ETS, emission trading

1 Introduction

The EU Emissions Trading System (EU ETS) has the objective to achieve the EU's carbon emission goals at minimum cost. Instead of imposing a tax to reach a certain goal, the policy determines a goal and lets the market determine the equilibrium price, which many economists have been advocating for a long time. Ideally, as this system ensures that all firms incur the same marginal price for emissions, abatement should be realized where it is cheapest so that the aggregate abatement cost is minimized. However, abatement costs are not the only costs arising from an emission trading scheme: just like any other regulation, this measure 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, even many firms themselves do not account explicitly for the value of their employees' time and resources spent in the course of EU ETS compliance optimization. As a result, transaction costs are mostly ignored both in academic and in policy discussions about emission trading. This study uses firm-level data to estimate these transaction costs and argues that their magnitude is relevant for many of the smaller regulated firms and should thus be taken into account when assessing the efficiency of the EU ETS.

In order to identify these transaction costs, I exploit an important aspect of EU ETS regulation: in order to favor the development of a global emission trading system, the EU ETS has been linked to the international certificate market created by the Kyoto protocol. This protocol creates the possibility to receive "offset credits" in return for emission savings in many parts of the world; these credits can then be sold and used to account for

firm-level emissions in the EU ETS, as well as for state-level emission in the international Kyoto system. On the aggregate, these additional credits increase the cap for European polluters and decrease their compliance cost. Offset credits have been cheaper than the EU Allowances (EAs) all through phase II of the EU ETS (2008-2012). The quantity of offset credits used in the EU is limited by a firm-specific offset entitlement fixed by the regulator. For the firms, offset usage was simply a way to reduce compliance cost. In this context, it is puzzling that a considerable share of regulated firms did not use any offset credits.

This study provides both a descriptive and an analytical contribution to the literature. First, this study describes the observed offset usage behavior and gives an overview of how much firms could have saved in compliance cost if they had all used their offset entitlements. Among firms that failed to participate in this profitable offset market, there are mostly small firms and more particularly those firms with relatively generous free allocations of European certificates. Across firms, forgone profits add up to around €1.35 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 presence of some unobserved costs: transaction costs, as defined in this study, can include employees' salaries, on-the-job training and consultancy costs. They are assumed fixed and payable whenever a firm first decides to engage in offset trading or emission trading in general. It is important to estimate these costs in order to evaluate *if* they play a role for firm behavior, and identify more particularly *for which* firms.

The theoretical model lays out how transaction costs change the firms' optimization problem. It establishes that such costs can make the firms' free allocation of permits non-neutral, so that firms with large allocations relative to their emissions enjoy the advantage of facing smaller transaction costs and being more likely to use their offset entitlement (additionally to the obvious benefit of receiving a large transfer of valuable permits). The model establishes a link between, on one hand, the decision to participate in the offset market and, on the other hand, 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 relationship to estimate the unobserved transaction costs necessary to rationalize firms' decision not to participate in the offset market. The distribution of these costs appears highly skewed, so that a regression at the mean may not be very informative. I use a binary quantile regression to estimate several quantiles of the transaction cost distribution.

The empirical results suggest that participation in the offset market seems on average cost-free for those firms which have already been constrained to actively trade EAs because their allocation is not generous enough. For the remaining firms, those which can comply with their EU ETS obligations without buying any certificates, average fixed transaction costs are estimated around €24 000. The quantile regression provides a more complete view of the distribution of transaction costs. It shows that median costs are different from zero for both groups of firms, with €3 000 for short firms and €14 000 for long firms. The difference between median and the much higher mean cost for long firms is mostly driven by the 10% of firms facing the highest costs, for which however the estimates have large standard errors. Although transaction costs are relatively small compared to many firms' turnover, they make active participation unprofitable for the smallest 23% of firms. For most bigger firms, investment in offset certificates remains profitable.

The theory of the offset market as a "spatial flexibility mechanism" has been explained by Stevens and Rose (2002). Empirically, Trotignon (2012) describes how offset have been used in the EU ETS and shows that firms initially used few offsets until a sharp increase in 2011. 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).

While the abatement incentives of such a cap-and-trade scheme have been amply discussed, most of the literature makes strong assumptions on the absence of frictions and costs arising from practical management of compliance. It has been clear since the seminal paper by Coase (1960) that the fundamental mechanism of such a trading scheme relies on the absence of transaction costs. The theoretical importance for cap-and-trade regulation of such "costs to use the price mechanism" has been modeled by Stavins (1995) and Montero (1998). Stavins (1995) shows that a major problem arising from transaction costs is that they make initial allocation non-neutral, so that free allocation (like in phase II of the EU ETS) has an impact on the resulting market equilibrium. Montero (1998) moreover adds the impact of uncertainty. The theoretical section of this study draws on this work, although the model has been modified to account for two different types of certificates and take into account only fixed costs (i.e. marginal transaction costs are set to zero).

Empirical evidence on transaction costs in environmental policy is relatively scarce, as McCann et al. (2005) regret in their literature review on this topic: transaction costs are rarely evaluated, maybe simply because they are by nature unobservable. Literature suggests that transaction costs and other market imperfections have hampered the impact of US environmental trading programs (Tietenberg, 2006; Hahn and Hester, 1989). Concerning the EU ETS in particular, it is found in general that small firms trade more “passively” and that many firms seem to lack institutional capacity for optimal trading (Sandoff and Schaad, 2009). 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; Löschel et al., 2010, 2011). This seems to support the idea of fixed transaction costs. This study aims at estimating an order of magnitude for transaction costs, in order to assess whether these costs are relevant for the functioning of the EU ETS.

The methodology used in this study approaches the problem in a completely different way than surveys. Anderson and Sallee (2011) identify marginal costs of regulating fuel-standards by observing to what extent automakers use a regulatory loophole of known costs to avoid the fuel-efficiency standards. Conceptually, this is close to my study which identifies fixed costs by observing on the opposite which firms forwent the benefits of a profitable loophole to avoid trading. The binary choice methodology used in this study relates to the revealed-preference techniques used in nonmarket (contingent) valuation of environmental goods (Bennett and Blamey, 2001). However, the firm size distribution is strongly skewed and the fit of parametric models is poor, so that I rather estimate semi-parametric binary quantile model. Quantile models have been developed by Koenker and Bassett (1978), but only recently have they been applied to binary choice (Kordas, 2006). Belluzzo Jr (2004) applies them to estimate a full distribution of willingness-to-pay (for some public good) in a population, which is symmetric to this study: transaction costs are measured here from the “unwillingness-to-benefit” of firms.

The remainder of this article is organized as follows. After explaining 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). 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 then gradually extended by adding entry costs (section 3.2 and 3.3). Finally, I present the data and some stylized facts (section 4), explain the methodology (section 5) and estimate the distribution of transaction costs (section 6).

2 Background information on the EU ETS and offset credits

2.1 Institutional framework

In order to analyze firm behavior in the EU ETS, one first has to understand the legal framework of this trading scheme. In a common effort to reduce greenhouse gas emission, the member states of the European Union have put into place the EU ETS. In order to “internalize” carbon dioxide externalities, a market for carbon emissions has been created: the EU gives out a limited number of emission certificates, which can subsequently be traded which has been coined the “cap-and-trade” principle.

During phase II of the EU ETS, firms receive EU allowances (EUAs) free of charge by their national governments¹ and can then trade them among each other on the secondary market.² Firms are not obliged to hold any allowances over time, as long as they can provide a sufficient number of certificates on the last day of the year: one for each emitted ton of CO₂. Given this equivalence, quantities of certificates are commonly measured in tons of CO₂ equivalent (tCO₂e). The data is observed once a year, summarizing emissions and surrendered certificates over the year. Once a certificate, European or international, has been surrendered, it disappears from the market and cannot be used again.

Economics literature going back to Coase (1960) has argued that initial allocation of property rights on the externality does not matter. In practice, the EU Commission planned initially to auction the permits, but finally opted for handing them out free of charge based on companies’ historical emission levels, a practice called *grand-fathering*. Much of the literature on the EU ETS concentrates on initial allocation and its consequences, or its

¹In phase II, virtually all allowances were given out for free; some allowances were auctioned, but their overall amount is negligible.

²In fact, many firms have company-internal rules limiting buying and selling to avoid speculation and financial exposure to price variations (Heindl, 2012)

irrelevancy.

The EU ETS is conceived to be the local counterpart of an international initiative framed by the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto protocol. In order to strengthen this link, emission certificates created under the Kyoto protocol's flexibility mechanism are included into the European system: since 2005, European firms can satisfy part of their emission obligations by surrendering Certified Emission Reductions (CERs, from Clean Development Mechanism (CDM)) or Emission Reduction Units (ERUs, from Joint Implementation projects (JI)). CERs and ERUs are commonly called *international offset certificates*.³ They are mostly produced outside the EU and draw their validity from UN control and certification.

In order to ensure that the main emission reduction effort is provided domestically, the EU directive limited the overall usable amount of offset certificates. During phase II of the EU ETS (2008-2012), EU member states were free to set an allowed amount of offset credits to be used by its firms. This amount was defined as a percentage share of *allocated* certificates at the plant level. By not conditioning on *actual* emissions the regulators aimed at keeping the overall amount limited and ensuring incentive-compatibility. Firms were entitled to use this fixed amount of offsets during phase II, i.e. before April 2013. Entitlement shares differed substantially across member states and several countries further restricted the temporal flexibility by setting annual limits, cf. table 5 on page 24.

Considerable uncertainty surrounded the future of both the Kyoto protocol and the right to use offsets within the EU ETS beyond the end of phase II in 2012. For the supply side, it was clear that no more ERUs could be created from 2013 onwards, whereas the future of CER creation was unclear.

In April 2009, a EU directive called for a harmonization of the heterogeneous offset quantity limits across member states, claiming that generous limits gave some countries' firms unfair advantages. The directive also extended the validity of offset entitlements into phase III ("bankability"), without determining details of this extension. It also raised the minimum allowed offset amount to 11% of entitlements between 2008 and 2012 or to 4.5% of emissions for new entrants. However, formulation was cautious and details not fixed yet. In 2011, the Commission decided that CERs from industrial gas projects should not be valid within the EU ETS in phase III.

The legislation making offset entitlements definitely bankable into phase III (2013-2020) was finally passed only in November 2013. Given that the previous regulation on offset entitlements had ended in April 2013, this leaves a considerable lapse of time in which the continuation of the system was granted but legally binding details were not known. The new legislation states that firms can use in total over 2008-2020 the highest of the following:

- The international credit entitlement specified in the national allocation plan in phase II; or
- 11% of the free allocation of EU allowances granted to them in phase II; or
- 4.5% of their verified emissions in phase III.

The first two points simply aim at ensuring equity for companies from different countries. The last point is aiming at new entrants and firms considerably extending their activity; it barely impacts firms already established in phase II.

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

International credits cover emissions which 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, esp. developing countries) and have the abatement credited *via* the use of offset credits for their EU-located plants. Stevens and Rose (2002) argue that this spatial trading allows for much bigger efficiency gains than what can be expected from inter-temporal flexibility, i.e. firms' ability to bank or borrow emissions over time. As a side effect, 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 will determine

³As CERs and ERUs can be used interchangeably under this legislation, I will from now on only use the terms "CER" or "offset" while everything applies equally to ERUs as well.

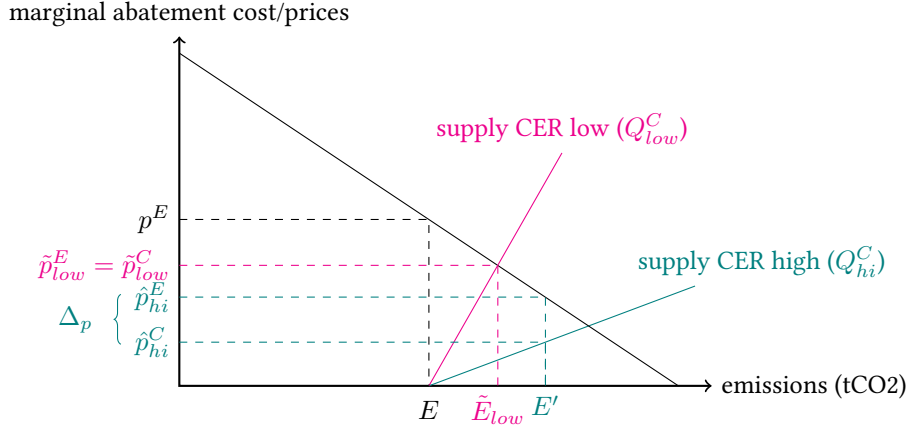


Figure 1: Aggregate market equilibrium, with two alternative CER supply levels

the overall amount of certificates available.

The resulting market equilibrium is illustrated in figure 1: without offset credits, the standard result holds, so that the market clears at the regulated maximum emission level E at price p^E , equal to the marginal abatement cost at E (Trotignon, 2012). Offset certificates are perfect substitutes to EUAs up to the regulatory quantity limit. When CERs are expensive to produce (supply Q_{low}^C), their availability increases the overall cap, lowers the price and moves the equilibrium to \tilde{E}_{low} , where prices equalize at the level for which CER supply clears. This equalizes EUA and CER prices $\tilde{p}_{low}^E = \tilde{p}_{low}^C$. If CER creation is cheap (supply Q_{hi}^C), firms would like to buy more offset certificates than allowed. The aggregate offset quantity limit E' is binding in that case. The resulting constrained equilibrium at E' , does not ensure equal prices anymore: EUAs trade at marginal abatement cost \hat{p}_{hi}^E of the new emission level E' . The over-supply of offset certificates drives their price down to \hat{p}_{hi}^C such that $Q_{hi}^C + E \leq E'$.

The price differential $\Delta_p = \hat{p}^E - \hat{p}^C$ is thus always positive; its magnitude depends on the “production price” of offset credits and stringency of the usage quantity limit. Although the model allows for $\Delta_p = 0$, abatement is much cheaper in unregulated regions so that in practice Δ_p is always strictly positive.⁴ Note that EUA and CER prices are not equalized; nevertheless, the introduction of offset credits reduces EUA prices from p^E to \hat{p}_{hi}^E .

Finance literature has analyzed the price dynamics of secondary CERs (sCER), i.e. CERs that are on the market already and not directly sold by an offset project. Mansanet-Bataller et al. (2011) find that EUA prices are the main “money” in the carbon market, determining the fluctuations of CER prices. The differences between both prices, the spread, is not constant though: CERs are relatively expensive if EUA price is high and trading volumes increase if the spread is high. They conclude that the EUA-sCER spread is used for arbitrage by market participants. Nazifi (2013) on the opposite fails to find any price convergence or co-integrated relationship between CER and EUA prices.

2.3 Definition of transaction costs (as used in this study)

Much of the arguments in favor of emission trading are derived from Coase (1960) and its application to environmental policy by Montgomery (1972) and Baumol and Oates (1971). The most cited advantages are cost-efficiency and irrelevance of initial allocation for the final equilibrium. However, emission trading – just like any other market transaction – is unlikely to be completely free of transaction costs. Coase’s main point in this work was to underline that the irrelevancy of initial property allocation for final resource allocation holds only if frictions are negligible. This study follows his broad definition of these frictions as the “general cost to use the price mechanism”, implying a vast diversity of costs such as information, management, contracting and other transaction costs.

⁴The alternative case, where $\Delta_p = 0$, simplifies into the basic case with only one type of certificates, so that it is not interesting for our analysis.

The theoretical work on transaction costs in emission trading is based on Stavins (1995) and Montero (1998). In practice, cost-efficiency gains from emission trading schemes are often claimed to be below expectations. Atkinson and Tietenberg (1991) argue that trading has been too scarce to reach a cost-efficient outcome; they argue that this inefficiency stems from the bilateral, sequential nature of trades (instead of a simultaneous centralized market). To my knowledge, virtually all empirical papers evaluating the magnitude of such transaction costs in the EU ETS have worked with survey data (Jaraite et al., 2010; Heindl, 2012; Schleich and Betz, 2004; Löschel et al., 2010, 2011). Jaraite and Kazukauskas (2012) are an exception as they use transaction data from phase I (2005-2007), which was 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.

Schleich and Betz (2004) underline that allocations are so generous that the average need for additional permits for SME is only about 1 250 tCO₂e per year, an amount at which participation costs are likely to be higher than the actual amount at stake. Similarly, Jaraite et al. (2010) estimate that average participation costs of the largest firms were €0.05 per tonne of emissions, while they were up to €2 per tonne for small firms. This difference supports the idea, that the major part of transaction costs is fixed rather than proportional to emissions. It remains unclear how to measure such unobserved costs; as McCann et al. (2005) regret most literature on transaction costs of environmental policies concentrates on agency/government cost, while few examine the cost incurred by stakeholders impacted.

The observed trading pattern gives another hint that entry costs are potentially relevant: it appears that firms trade very rarely and most transactions take place between plants belonging to the same firm (Zaklan, 2012; Jaraite and Kazukauskas, 2012). Again, transaction data needed for such analysis is only available for the phase I of the EU ETS.

As Heindl (2012) explains, the EU ETS produces costs through different channels:

- monitoring costs, as firms have to observe and report their emissions (which before were largely unknown),
- service charges of the EU registry (“formal” administrative costs),
- salaries of people employed by the firm for trading and information gathering,
- bargaining, contracting and transaction fees of the actual trading transactions.

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 the actual transactions and might explain why firms do not venture into the offset market. In the following, the term transaction cost will be 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, broker fees, etc. It *does not* include monitoring and reporting of emissions, administrative cost for EU/national agencies, and generally any other “unavoidable” cost. 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), in particular it does not take into account what Joas and Flachsland (2014) call “public-sector costs” incurred by the regulatory authority.

Defined in this way, the bulk of these costs are likely to be fixed, rather than proportional to transaction size. Indeed, the official transaction costs charged by brokerage firms for the sale of a certificate per ton (tCO₂e) are positive but small.⁵ Indirect costs arising from the hiring of additional personal and the acquisition of the necessary know-how are more relevant and easily scalable; electronic transactions finally make it equally easy to transfer one or a thousand certificates by one single person.

These participation costs are *a priori* unobservable. However, a multitude of firms providing information (Point Carbon), consulting firms (ICIS/Tschach) and financial transaction services (brokerage like TFS Green, exchange platforms like ICE) has emerged. It indeed seems like information is *a priori* an under-provided public good, until for-profit organizations like financial consulting firms step in to provide exclusive information to their clients. As the final transaction is virtually costfree, 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,⁶ while

⁵Convery 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.

⁶This information is downloaded from <https://www.theice.com/fees>.

an individual transaction thereafter costs only cents.

3 Model

Compliance to the EU ETS regulation increases the production cost of firms and changes its shape. The model developed here shows firm's optimization problem in presence of two types of emission certificates and examines how incentives and optimal behavior change in presence of participation costs. Simply put, firms always want to use cheap offset credits, unless transaction costs are prohibitively high compared to potential profits from using cheap offset credits. As potential loophole-profits are known from multiplying international offset entitlements by the price spread, this will allow us to estimate the size of transaction costs.

3.1 Emission 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.⁷ This subsection defines the reference case of emission trading with two types of certificates without participation costs. It introduces the notation and shows that firms can separate the decision of optimal emission levels (and produced quantities) from the partitioning between EUA and CER certificates. This simple remark will considerably simplify analysis in the subsequent entry cost sections (sections 3.2 and 3.3).

In absence of offsets, it is straightforward and has been shown (e.g. by Montgomery, 1972) that there is a market equilibrium ensuring that marginal abatement cost is equalized across firms and equal to the EUA price p^E . In this slightly more complex version including two types of certificates, EUAs and CERs, each firm i solves the following optimization problem:

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

$$\text{subject to } E_i = Q_i^C + Q_i^E, \quad (2)$$

$$T(Q_i^C, Q_i^E) = p^C Q_i^C + p^E Q_i^E, \quad (3)$$

$$Q_i^C \leq K_i, \quad (4)$$

where equation (1) is the profit maximization with $C(Y_i, E_i)$ the production cost, which depends on emissions E_i and output Y_i .⁸ I assume that increasing production Y_i (at a fixed emission level) increases cost $C_Y(Y_i, E_i) > 0$ and reducing emissions (at a given production level) increases cost $C_E(Y_i, E_i) < 0$.⁹ Q_i^C are the CERs surrendered in phase II and Q_i^E the surrendered EUAs. $T(Q_i^C, Q_i^E)$ is the direct cost of complying to ETS rules, i.e. the cost of buying the certificate quantities Q_i^E and Q_i^C necessary to justify the emission level E_i (equations (2) and (3)). Firms are given free certificates A_i at the beginning of phase II; they can sell superfluous certificates at market price p^E .

Equation (4) is the regulatory limit of the quantity of CERs used for firms with the firm-specific constant K_i ; it will depend on the CER supply whether demand is limited by this quantity constraint or a standard offer and demand situation involving equation (6). The overall amount of EUAs in the market is fixed by total allocations:

$$\sum_i A_i \leq \sum_i Q_i^E, \quad (5)$$

$$\sum_i Q_i^C \leq Q_{supply}^C(p^C), \quad (6)$$

The firm has to solve three problems simultaneously: decide on the optimal produced quantity Y_i , fix the optimal emission level E_i (depending on quantity and cost function $C(Y_i, E_i)$) and divide compliance (i.e. an

⁷Note that allocations and offset entitlements for the whole period were known to the firms before the beginning (from the NAPs).

⁸Emissions E_i and output Y_i as well as all other variables are here summed over the whole phase II (2008-2012)

⁹ C_Y and C_E denote the partial derivatives

amount of certificates equal to E_i) between offset and European certificates. This section intends to show that under fairly generous assumptions, the arbitrage between CERs and EUAs is independent of the production decision and can be summarized as $T^*(E)$.

The first-order conditions require quantity to be chosen optimally given production cost $C(Y, E_i)$ and prices. Let us assume that the production function C is such that there exists a function $Y^*(E_i)$ giving the optimal quantity produced for any given emission level. On a competitive market, goods are priced at their marginal production cost, so the output level is such that:¹⁰

$$\frac{\partial C(Y^*(E_i), E_i)}{\partial Y} = p \quad (7)$$

Compliance cost $T(Q^C, Q^E)$ 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:

$$\begin{aligned} -\frac{\partial C(Y^*(E_i), E_i)}{\partial E_i} &= \frac{\partial T}{\partial Q^C} \frac{\partial Q^C}{\partial E_i} + \frac{\partial T}{\partial Q^E} \frac{\partial Q^E}{\partial E_i} \\ &= p^C \frac{\partial Q^C}{\partial E_i} + p^E \frac{\partial Q^E}{\partial E_i} \end{aligned} \quad (8)$$

The compliance cost arises from an optimal splitting of certificates between EUAs and CERs, given the price differential and the quantity restriction on CERs. The marginal cost is either p^E or p^C depending on which sort of certificate is used to cover the last (marginal) emission. As previously seen, CERs are a perfect substitute for EUAs up to a certain quantity limit; their price is thus at most as high as an EUA's price, but never higher. For the purpose of this study, I will 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.¹¹

$$p^C < p^E$$

$$\text{or equivalently } \Delta_p > 0, \text{ where } p^E - p^C =: \Delta_p \quad (9)$$

The result is straightforward and illustrated in figure 2: at equal "utility" and lower price, offset credits are clearly preferable to EUAs, up to the regulatory quantity limit. Only if emissions are above K_i , the firm will comply for remaining emissions by using the more expensive EUAs.

$$Q_i^C = \begin{cases} E_i, & \text{if } E_i \leq K_i \\ K_i, & \text{if } K_i < E_i. \end{cases} \quad (10)$$

In this least-cost reference scenario, firms always use offset certificates. The compliance cost can be simplified to $T^*(E_i)$ giving for each emission level E_i the cost resulting from an optimal repartition between EUAs and CERs. In this simple case :

$$T^*(E_i) = \begin{cases} p^C E_i, & \text{if } 0 < E_i \leq K_i \\ p^E (E_i - K_i) + p^C K_i, & \text{if } K_i < E_i. \end{cases} \quad (11)$$

Once this result about the optimal repartition of certificate types is acknowledged, the firm's problem is much simplified:

$$\max_{E_i} \pi = pY^*(E_i) - C(Y^*(E_i), E_i) - T^*(E_i) \quad (12)$$

The problem of equations (11) and (12) separates the decision on optimal behavior in two steps: in a first step, firms decide on an optimal production level Y_i^* and optimal emissions E_i^* depending on the shape of their cost function $C(Y_i, E_i)$, marginal compliance cost $T^*(E_i)'$ and p . In a second step, the problem of choosing between offset and "normal" credits is trivial, as firms *always* want to use all their (cheaper) offset entitlement and use EUAs for the remaining emissions up to E_i^* as in equation (11).

¹⁰The competitive market hypothesis simplifies this equation, but is not needed for the subsequent argument, as long as there is a single equilibrium quantity $Y^*(E^*)$.

¹¹Moreover, the data reveals that in practice there has always been a clear price discount for offset certificates.

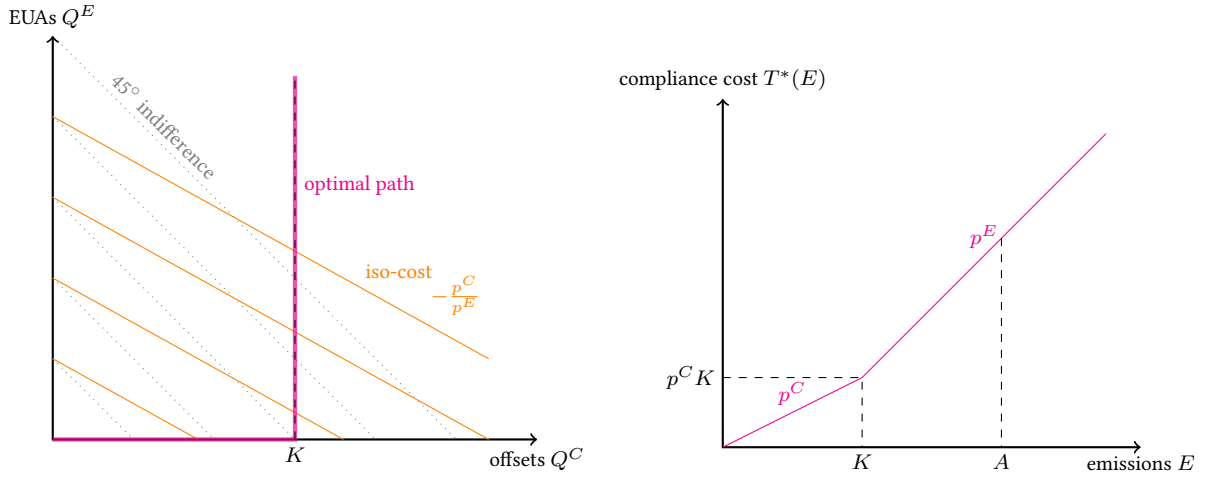


Figure 2: Deciding on the optimal quantity of EUAs and CERs (no entry cost, reference case)

By design, the offset quantity limit K_i was relatively small compared to actual emissions. In practice, a large majority of firms needs to use EUAs as well as (amply available) CERs, so that the quantity limit in equation (4) is binding for most firms. The central result that marginal abatement cost should be equalized across firms at the price level p^E remains valid.

3.2 Entry costs for the offset market

We will now see how fixed participation costs on the offset market change the firm's problem. The expression for profit remains the same as in equation (12), that depends on $T^*(E_i)$, assuming an optimal choice of the actual quantities Q^C and Q^E of each certificate type at emission level E . However, this optimization changes because compliance cost now includes a fixed cost T^C , which is incurred only if the firm uses *any* offset certificates. If the firm decides to use offset credits, its compliance cost is moreover reduced by an amount equal to the price spread Δ_p multiplied by the number of offsets:

$$T(Q_i^C, Q_i^E, E_i) = p^C Q_i^C + p^E Q_i^E + \mathbb{1}^C T^C \quad (13)$$

$$= p^E E_i + \mathbb{1}^C (T^C - \Delta_p Q_i^C), \quad (14)$$

where $\mathbb{1}^C$ iff $Q_i^C > 0$

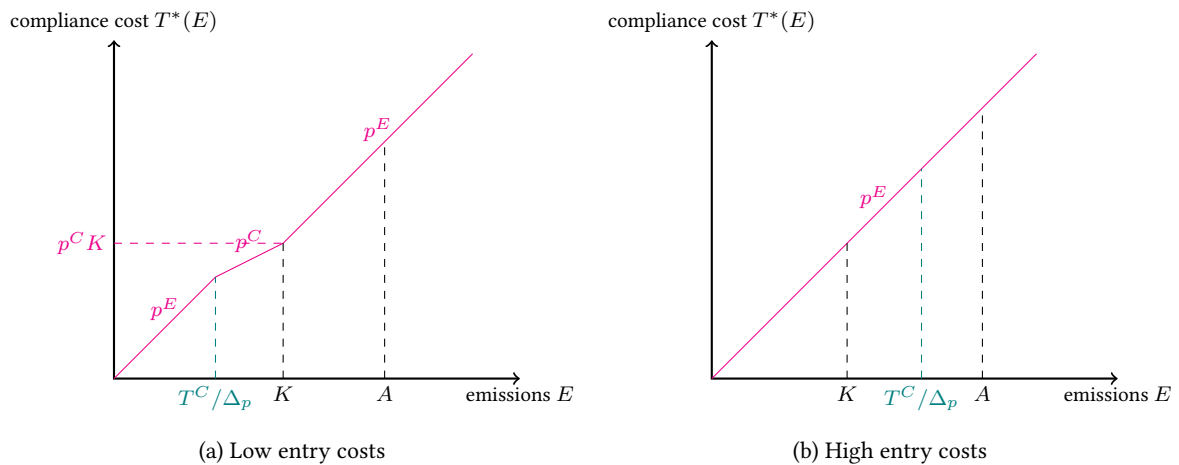


Figure 3: Deciding on the optimal quantity of EUAs and CERs (with entry cost for offsets)

Figure 3 shows that there are two scenarios. Either entry costs T^C are relatively low, i.e. such that $T^C <$

$\Delta_p K$. In that case (figure 3a), compliance cost $T^*(E)$ has two kink points: for low emissions, the potential profit is too small relative to the entry cost, $E\Delta_p < T^C$, so that only EUAs are used. Beyond that threshold, firms want to use only cheap offset credits up until quantity limit K_i . For all emissions after the first K_i tons, firms have to use EUAs by design. Alternatively, it is possible that entry costs are high, i.e. that $T^C > \Delta_p K$. In that case (figure 3b), firms never use offset credits and their marginal cost is always p^E .

$$Q_i^C = \begin{cases} E_i & \text{if } T^C < E_i \Delta_p \text{ and } E_i < K_i, \\ K_i & \text{if } T^C < K_i \Delta_p \text{ and } E_i \geq K_i, \\ 0 & \text{otherwise.} \end{cases}$$

Or put differently, by looking only at the binary decision to participate in the offset market:

$$\max_{\mathbb{1}_i^C, Q_i^C} \mathbb{1}_i^C (\Delta_p Q_i^C - T^C) \text{ such that } Q_i^C \leq K_i \quad (15)$$

Total overall cost changes, but at emission levels higher than K_i (where virtually all firms are located), the marginal cost remains at p^E . Participation costs do not directly impact the firm's optimal choice of emissions and output. The firm still equalizes marginal abatement cost and marginal compliance cost, which is still equal to p^E beyond K . There will be a second-order effect, as participation costs impact the demand for offsets: this decreases the CER price p^C and increases the EUA price p^E , which is however not informative on transaction costs and beyond the scope of this study.

3.3 Entry costs for both certificate markets

Let us finally consider a case in which firms face some entry cost to generally participate in the certificate market, i.e. setting up a trading department no matter the type of certificates, and an additional cost for the offset market. They can avoid both costs if they use only their freely allocated certificates. Obviously, firms with emissions bigger than their allocation will be forced to buy certificates and cannot avoid the general participation cost.

$$T(Q_i^C, Q_i^E, E_i) = p^C Q_i^C + p^E Q_i^E + \mathbb{1}^C T^C + \mathbb{1}^E T^E, \quad (16)$$

$$= p^E E_i + \mathbb{1}^E (T^E + \mathbb{1}^C (T^C - \Delta_p Q_i^C)), \quad (17)$$

$$\text{where } \mathbb{1}^C \text{ iff } Q_i^C > 0 \quad (18)$$

$$\mathbb{1}^E \text{ iff } Q_i^C > 0 \text{ and/or } Q_i^E > A_i \quad (19)$$

This formula reflects the idea that there is a general market participation cost (EUA or CER) plus an additional element for the CER market: a firm incurs general information entry costs T^E if it buys any certificates (CERs or EUAs), but needs to pay an additional information cost T^C to participate in the less well-known offset market.

This specification also implements the idea that firms which are "long", i.e. which got more free allocations than needed for their optimal output, 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. The impact of transaction costs depends on the relative magnitudes of T^C , $T^C + T^E$ and $K_i \Delta_p$.

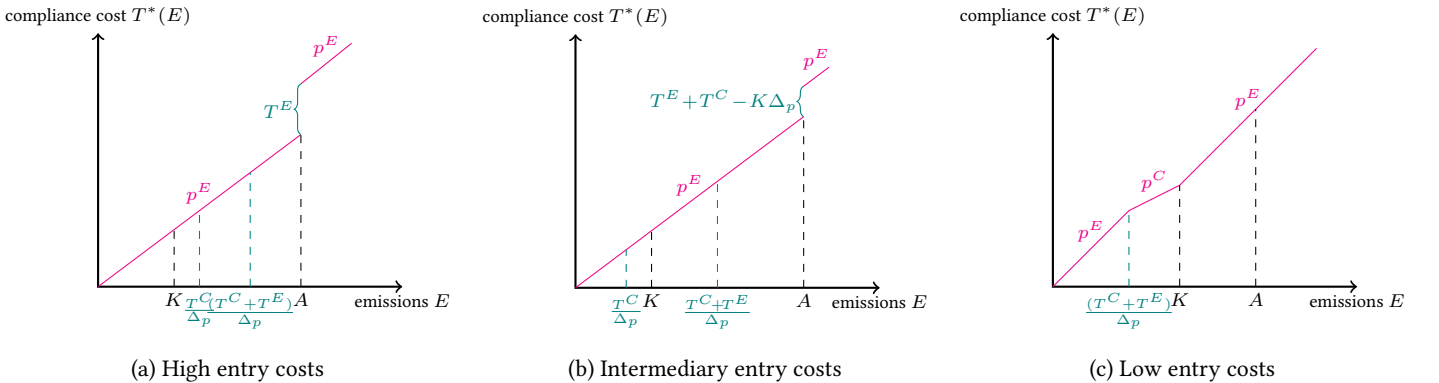


Figure 4: Deciding on the optimal quantity of EUAs and CERs (with entry cost on both markets)

Figure 4 illustrates this new situation. In figure 4a, offset entry costs are high so that $T^C > K_i \Delta_p$. 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 4b, T^C is relatively low, but $T^C + T^E$ is high, so that offsets alone are unprofitable. As $T^C < K_i \Delta_p$, firms which already incur entry price T^E (because $E_i > A_i$) will also buy offset certificates. There is thus a similar discontinuity as in 4a, but the jump is reduced from T^E to $T^E + T^C - K_i \Delta_p$, because the firm cashes in some gains from offset usage. Finally, figure 4c shows the situation if both entry costs are relatively low so that a firm uses offsets as soon as its emissions are above the threshold. The situation is similar to the one depicted in the previous section on figure 3a.

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. 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 .

It remains to be analyzed whether this jump causes firms to crowd at the lower level of the discontinuity, i.e. to restrict their emissions to A_i . The firm faces the same marginal cost p^E for emissions both below and above the jump of figure 4a and 4b, so 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 , so 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:

$$\Delta_\pi = \pi(Y^*(E_i^*), E_i^*) - \pi(Y^*(A_i), A_i) \quad (20)$$

$$= p(Y^*(E_i^*) - Y^*(A_i)) - C(Y^*(E_i^*), E_i^*) + C(Y^*(A_i), A_i) - T^*(E_i^*) + T^*(A_i) \quad (21)$$

By assumption, we are looking here at cases where $E_i^* > A_i$ and thus $Y^*(E_i^*) > Y^*(A_i)$; by definition of the optimal emission level E_i^* , Δ_π is always negative without the transaction cost terms of equation (21). As seen on figure 4, the change in incurred transaction cost is either T^E , as on figure 4a, or $T^E + T^C - \Delta_p K$ (which is smaller than T^E), see figure 4b.

From all that is known qualitatively about production functions, most technologies are such that the actual technological margin to reduce emissions without a complete corresponding reduction of output is limited. After all, emissions are just one production cost factor among many others and flexibility of the cost function is usually low (meaning that emission reductions are to a large extent matched by reductions in the produced outcome). Even for small difference between E_i^* and A_i it is likely that Δ_π is negative and large. A priori this case thus seems not so relevant in practice, but it nevertheless will need to be taken into account in the empirical section. A notable exception might be emission savings by electricity generating plants, as some firms have a scope for fuel-switching across different plants and emission costs are a more important cost factor in this industry. This sector will thus be examined more in detail. The assessment will be rather indirect: information on prices p and quantities Y are not available, so that neither cost function $C(Y, E)$ nor the profit change Δ_π will be estimated (see Appendix D). Instead, I will check that we do not observe any crowding around $E = A$.

For all firms which are not situated closely above the jump of the compliance cost function, this problem is not relevant as generally $\Delta_\pi > 0$. Let “allocation status” $\mathbb{1}_i^{long}$ be a dummy variable indicating that allocation A_i is larger than emissions E_i^* , such that the optimization problem simplifies to:

$$\max_{\{\mathbb{1}_i^C\}} \mathbb{1}_i^C (\Delta_p K_i - T^C - \mathbb{1}_i^{long} T^E) \quad (22)$$

$$\text{where } \mathbb{1}_i^C \text{ iff } Q_i^C > 0$$

A firm participates if it is worth incurring the entry costs, depending on the allocation status – long or short – of the firm. The empirical section will use the prediction that a short firm not participating must imply that $\Delta_p K_i < T^C$ and a long firm not participating shows that $\Delta_p K_i < T^C + T^E$, while the same inequalities are inverted for participating firms. Note that this solution still 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 still equalized across the large majority of firms at the level of p^E .

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

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. On the aggregate, p^E obviously depends on the introduction and the *de facto* adoption of 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^* . However, the general equilibrium effect of offsets on prices is not related to the transaction costs, so they are beyond the scope of this study.

4 Data and stylized facts

A preliminary descriptive data analysis reveals some stylized facts, that my empirical analysis will rely on: (a.) CER prices are indeed lower than EUA prices, (b.) a large majority of firms has emissions superior to their offset entitlement and inferior to their free allocation, (c.) a non-negligible number of firms does not use their offset entitlements (28%) and (d.) the size distribution of firms is very unequal.

4.1 ETS data

This study mainly relies on the data of the European ETS Registry 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 surrendered certificates (EUAs, CERs and ERUs) for *all* 13,590 plants subject to ETS compliance obligations. Moreover, plants have been matched to Bureau van Dijk's Orbis company database in order to understand the ownership structures that relate many of these individual plants.¹² This matching is important as the relevant decision is likely to happen at an aggregated firm level, even though regulation, allocation and offset entitlements are defined at plant level.

Plants from countries which do not participate in the standard way described in section 2.1 (Norway, Estonia, Liechtenstein; 135 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. Overall, there remain around 9,000 plants belonging to 4,762 firms. Almost 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 quota of CERs multiplied by the sum A_i of a plant's free allocations over phase II. The magnitude of this quota has been chosen by national governments, but the EU has restricted it to a maximum of 22%, as 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 ETS Registry in 2014.

On the one side, allocation A_i , and consequently its fraction K_i , have been so small that only a meager 2.8% of firms is able to comply by using CERs only. On the other side, allocations have been relatively generous so that 80% of the firms fall could cover all of their emissions using only grandfathered allocations.

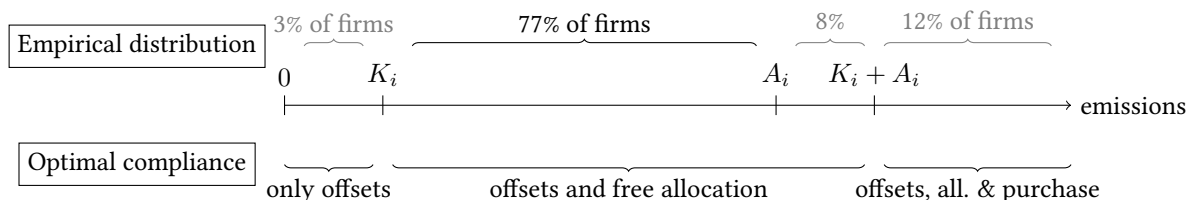


Table 1 shows some descriptive statistics of firms. Free allocation has on average been higher than emissions. The savings generated from using offset certificates instead of EUAs average around €764 000, while on average another €563 000 of potential savings remain unexploited. As will be explained more in detail, these high numbers result from a large majority with small savings and few firms with very high savings.

¹²For more information on this matching, see Jaraitė et al. (2013) or their website <http://fsr.eui.eu/CPRU/EUTLTransactionData.aspx>

	mean	p50	sd	min	max
Nb of countries active	1.14	1	0.73	1	16
Nb of plants	1.95	1	5.21	1	155
Free allocated EUAs (ktCO ₂ e)	2175.4	126.9	14566.8	0.015	380586.5
Emissions (ktCO ₂)	2129.5	92.4	17054.3	0.0030	563608.3
International credit entitlement (ktCO ₂ e)	301.0	13.8	2463.0	0.0010	91524.3
Used offset credits (ktCO ₂ e)	230.8	10.5	1575.2	0	55536.4
Savings from CER use (k €)	887.0	38.5	6150.1	0	217411.5
Unexploited profits from CERs (k €)	685.5	24.3	7782.0	0.0047	200316.1
Firms using all CER entitlement	0.51	1	0.50	0	1
Firms using no CERs	0.23	0	0.42	0	1
Observations	4086				

Table 1: Descriptive firm statistics

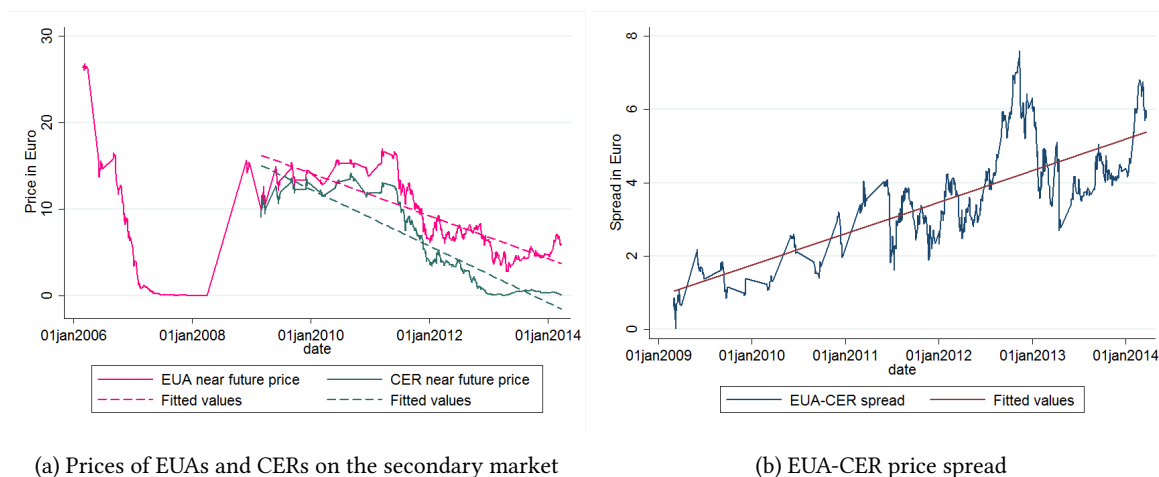


Figure 5: Prices of EU and offset certificates (source: www.theice.com)

4.2 Prices and savings

As argued before, CERs are expected to trade at an inferior price to EUAs or at best at equal price if the CER supply is relatively scarce. Indeed, CERs have always traded at a positive discount from EUAs. Figure 5 shows that the price differential was rather small in the beginning. After few months, the spread became clearer and CERs have been up to €7 cheaper than EUAs. The spread increased with time and was rather volatile.

This price spread has allowed firms to realize considerable savings, as shown on figure 6¹³. Altogether, firms have saved an overall amount of €3.7 billion. However, the additional unused 295 MtCO₂e certificates could have generated another €1.35 billion at 2012 prices.

These numbers take prices as given, so they cannot be interpreted as the “overall saving” for firms 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* realized savings from offset usage are probably higher than my estimates used in table 1. Stephan et al. (2014) estimate demand elasticity relatively high, so that actual firms’ savings are as high as €20 billion.

¹³This number is approximately computed by multiplying the annual average price spread with the amount of offset certificates surrendered in that year.

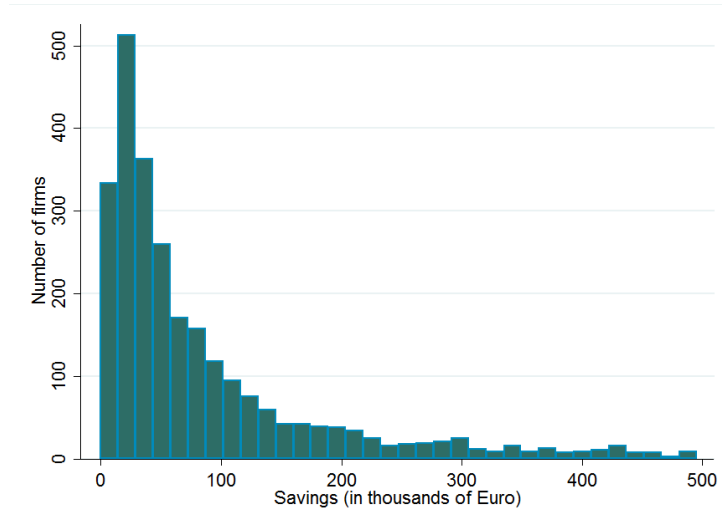


Figure 6: Histogram of realized savings from using offset credits (cut at €500 000 for better readability)

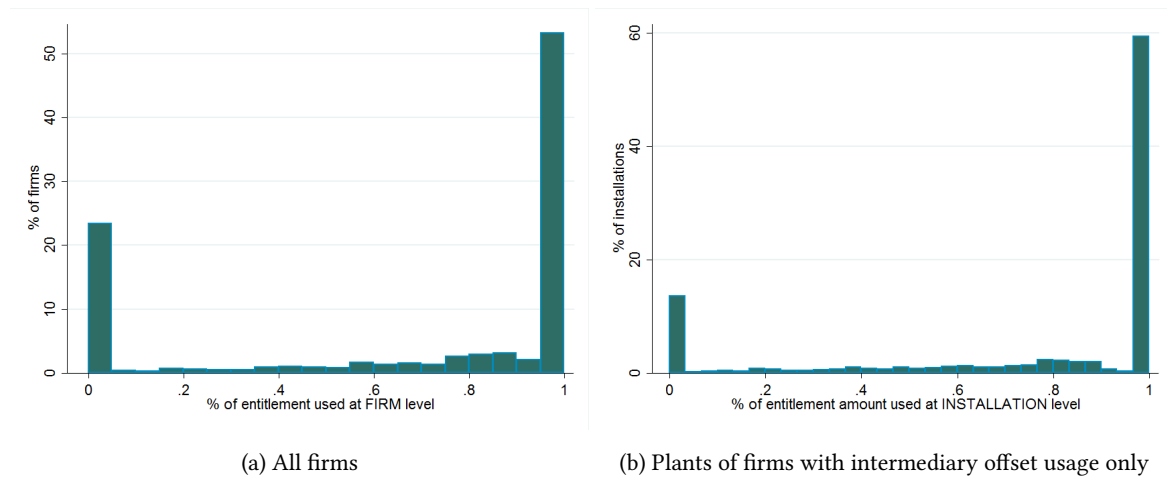


Figure 7: Ratio of used offset credits over overall offset entitlement

4.3 Evidence for transaction costs

As seen before, many firms did not use their offset entitlements. Given the broad supply of offset certificates (see Appendix for details, page 25) and their relatively low price, this is surprising. One potential explanation for firms not participating in the market could be that their expected pay-off was not high enough to cover transaction costs of information procurement, such as the cost of hiring additional personal 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 CER market and (c.) an increasing likelihood of participating in the offset market as firm size and offset entitlement increase.

Supporting the idea of fixed participation cost, firms have mostly followed an “all or nothing” strategy in their offset usage: the left-hand side of figure 7 shows the surrendered CERs as a percentage of the total offset entitlement. One can see two frequency spikes: about half of the firms use *all* their offset entitlements and over a quarter of the firms uses *none*. Finally the last quarter of firms uses some but not all of their offset entitlement. As explained, all firms could make a benefit by using their offset entitlements; it is thus puzzling that half of the firms chose not to use all of them.

While firm- and plant-level strategies seem largely aligned, firms who used only “some” of their offset en-

titlements usually did so by using plant-level tactics: either using all or none of a plants' offset entitlements. Overall, firms used on average 62% of their offset entitlement. By definition, firms participate fully only if all of their plants participate (51%) and do not participate if none of their plants participate (23%). More interestingly, multi-plant-firms with intermediary participation are mostly composed of plants participating fully or not at all, see figure 7b. A possible explanation would be that firms had to face plant- and firm-level transaction costs to participate in the offset market, which made it unprofitable for some firms but also for some individual plants not to participate.

The main consequence of transaction costs is that the make initial allocation non neutral (Stavins, 1995). Supporting the idea of such costs, initial allocation of EUAs impacts the likelihood to use offset certificates: there are 64% of *long* firms, i.e. with enough freely allocated EUAs to cover all of their emissions, and these firms have a higher tendency not to participate in the offset market. The simple t-test in table 2 shows that the means are different among participating and non-participating firms: 69% of non-participating firms are long, while this share is only 58% amongst participating firms.

	Participant	Non-participant	Significance level
Offset entitlement	390,248	6,407	***
Long ('enough' allocations)	.61	.69	***
Observations	3136	950	4086

mean coefficients

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2: T-test for equality of means in size and allocation status, by offset usage

Many of these costs are likely to be of fixed rather than not proportional to firm size. Firms with large credit entitlements should therefore participate more as the entry costs become small compared to the potential gain, which is confirmed by the t-test in table 2. All firms with potential profits larger than €330 000 use their offset credits, and over 95% of non-participating firms have a potential profit below €100 000, with a median at €12 300. This gives us an order of magnitude of avoided transaction costs.

Figure 8 shows the interaction between the size and the allocation effect: at lower size deciles, firms use relatively little offsets, 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.

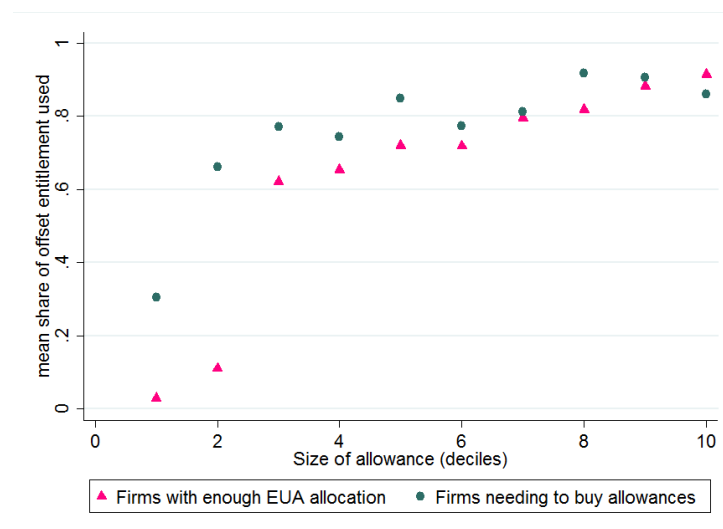


Figure 8: Offset usage by allocation and according to size deciles of offset entitlement (=potential profit)

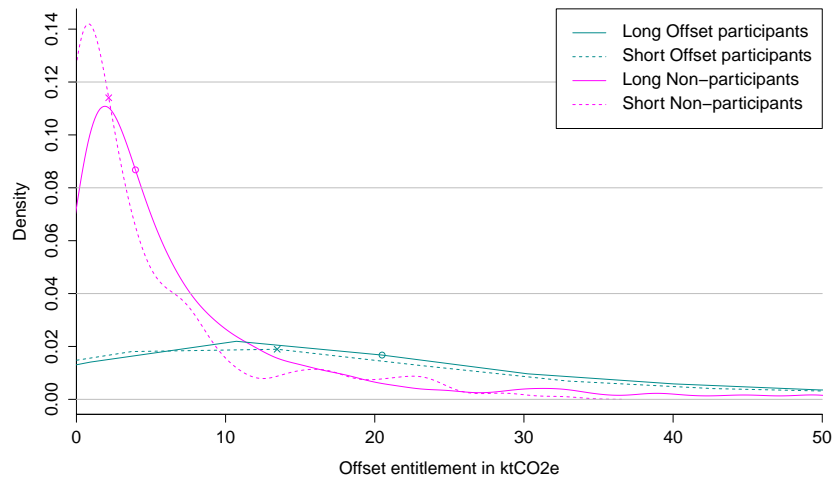


Figure 9: Distribution of offset entitlement in the different groups of firms

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 ktCO_{2e}, although both densities continue beyond. Crosses and circles indicate median values.

Assuming that firms take a rational decision, plants that do not participate must estimate their participation cost to be *higher* than their potential profit, so that the mean offset entitlement time 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 9 shows that the means are clearly different. In general non-participating firms tend to be smaller, with over 50% of firms below 3 500 tCO_{2e} of offset entitlements. Nevertheless, the distributions both stretch out until above 50 000 tCO_{2e}, showing that the separation is not clear cut. The largest non-participant firm has 94 000 tCO_{2e} entitlement, and the 16 percentiles of the 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.

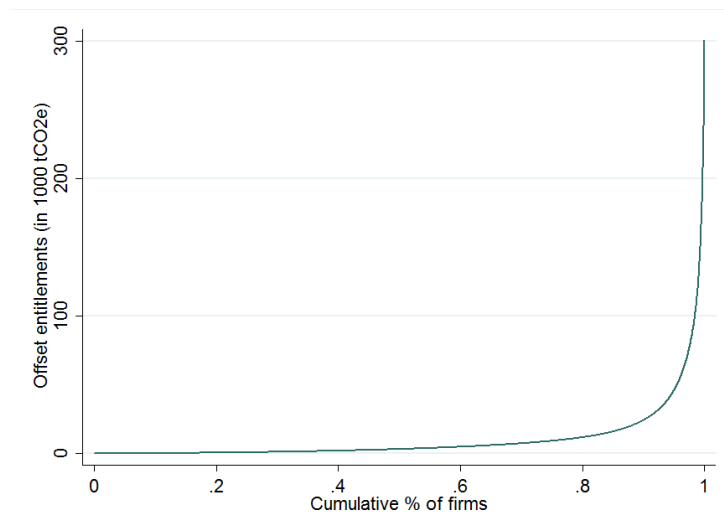


Figure 10: Lorenz curve of offset entitlements

As the reader might have already noted in figure 9, the size distribution of firms is highly unequal. This is illustrated in figure 10 that draws the Lorenz curve for offset entitlements, but similar inequality is true for emissions, number of plants and grandfathered allocations. The empirical methods used will need to be chosen

such that they do not overweight these rare and extremely large outlier firms.

5 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^C and $(T^C + T^E)$ relative to the known quantities A_i , E_i and K_i . This can be described by a binary choice model where T^C and T^E are latent variables and K_i is the firm-specific cut-off value relevant for the decision to participate. This normalization methodology allows us to interpret T^C and T^E in terms of units of K_i (tCO2e or euros). This method to use preference revelation is similar to the methodology of contingent valuation. However, this estimation uses observed behavior and exploits the fact that we have variation in potential profit for different firms. This study does not use survey methods such as those common in this literature (i.e. I am working with revealed preferences rather than stated preferences). I keep assuming that no individual firm has any market power so that they do not have to consider their own impact on price. The basic relationship exploited here is:

$$\mathbb{1}_i^C = \mathbb{1}\{K_i > T^C + T^E \mathbb{1}_i^{long} + \epsilon_i\} \quad (23)$$

If the error term is assumed to be iid following a normal distribution, equation (23) describes a probit model in which coefficients are normalized in a way that the coefficient of the potential profit is equal to 1. The other coefficients measure transaction costs in tCO2e and a simple multiplication by the price spread per tCO2e gives us the relevant figures in euros. This relates to the contingent valuation literature, where willingness-to-pay for certain attributes is usually estimated by normalizing the utility of income to 1. Alternatively, the error term can be assumed to follow a logit distribution, leading us to (normalized) logit model.

However, 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. Moreover, some firms with very high K_i still do not exploit their offset entitlement, so that the distribution of ϵ is likely to have some large 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:

$$\sigma_i = \exp(K_i \gamma) \quad (24)$$

However, this method still stems its identification from functional assumptions and, more importantly, estimates only the mean transaction costs. Given the few large outliers, these mean transaction costs appear high. Following empirical work from Kordas (2006); Belluzzo Jr (2004), I estimate a full range of binary quantile regressions to analyze not only the mean but the whole distribution of transaction costs. This semi-parametric method is more robust to non-symmetric error distributions, so I can verify whether this assumption of the probit model is reasonable.

Following the methodology of Kordas (2006), I estimate a binary quantile model. For this, I define the conditional quantile $Q(\tau)$:

$$Q_{\{\mathbb{1}_i^C\}}(\tau | \mathbb{1}_i^{long}, K_i) = \mathbb{1}\{K_i \geq T_\tau^C + T_\tau^E \mathbb{1}_i^{long}\} \quad (25)$$

The parametric probit or logit draw their identification from the conditional mean assumption $E(\epsilon_i | x) = 0$, while the following methodology estimates the median and thus is identified over the assumption that the median conditional error is zero. A simple estimator that illustrates the mechanic is the maximum score estimator from Manski (1975) with $\tau = .5$, which simply maximizes the number of “right predictions” using an indicator function:

$$\max_{T_\tau^C, T_\tau^E} S_{n\tau}(T_\tau^C, T_\tau^E; K_i) = n^{-1} \sum_{i=1}^n [\mathbb{1}_i^C - (1 - \tau)] \mathbb{1}\{K_i - T_\tau^C - T_\tau^E \mathbb{1}_i^{long} \geq 0\} \quad (26)$$

Similarly to the median with $\tau = .5$, we can estimate the other conditional quantiles. While this estimator is intuitively appealing for its simplicity, its discreteness makes it difficult to optimize and determine standard errors. To solve this problem, Horowitz (1992) has formulated a smoothed maximum score estimator using some

kernel function to overcome the continuity problem. He provides comprehensive asymptotic theory for this estimator, which has been extended to other quantiles than the median by Kordas (2006). The smoothed binary quantile estimator at quantile $\tau \in (0, 1)$ is the solution to the problem:

$$\max_{T_\tau^C, T_\tau^E} S_{n\tau}(T_\tau^C, T_\tau^E; h_n) = n^{-1} \sum_{i=1}^n [\mathbb{1}_i^C - (1 - \tau)] \Phi \left(\frac{K_i - T_\tau^C - T_\tau^E \mathbb{1}_i^{long}}{h_n} \right) \quad (27)$$

where $\Phi(\cdot)$ is a continuous, differentiable kernel function and h_n an appropriate bandwidth. Results allow for checking whether the functional assumption of the probit or logit is reasonable.

6 Estimation

If the error term ϵ_i is normal, the model becomes similar to a standard probit model. The results of this estimation are shown in table 3. The same table also shows the very similar results estimated with a heteroskedastic model, allowing error variance to scale with entitlement magnitude.¹⁴ The costs indicated are measured in tCO2e of offset entitlement, i.e. they have to be multiplied by the average price spread of €3.60 to give a monetary value in euros. The estimate for T^C , the transaction cost for offset usage, is not significantly different from zero: this suggests that those firms that are already obliged to buy certificates on the normal EU ETS market have on average no additional cost of offset trading. However, the estimate T^E indicates that the other firms, which are not buying EUA credits anyways, face on average a relatively high cost around €24 000 (=7 000*3.60) for engaging in offset trading activity.

	Probit	Heterosk. probit	Logit	Heterosk. logit
T^C	-2004 (-1.75)	-1888 (-1.70)	5.66 (0.01)	19.06 (0.03)
T^E	7004*** (7.26)	6939*** (7.32)	5858*** (8.52)	5848*** (8.53)
σ	16247*** (9.76)	15983*** (9.97)	7269*** (12.00)	7245*** (12.04)
γ		2.94e-07*** (29.30)		8.75e-08*** (24.27)
N	4086	4086	4086	4086
r2	.264	.264	.284	.285

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

Table 3: Parametric mean estimates for transaction costs

As argued before, the binary quantile regression gives a more complete overview over the distribution of transaction costs. As the estimation of this model involves the optimization over a complex function, I use Kordas' S-Plus/Fortran code to perform simulated annealing following the algorithm of Goffe et al. (1994). With a large sample such as the one used in this study, results turn out to be very similar to Manski's discrete quantile maximum estimator.

The results of table 4 are graphically summarized in figure 11: for short firms, then median cost is estimated at 947 tCO2e, i.e. around €3 400. While transaction costs are indistinguishable from zero for the lower quantiles of the transaction cost distribution, their values are high at the lower ends. According to these estimates, some firms are willing to forgo as much as 24 800 tCO2e offset entitlement, or €89 000,¹⁵ at the higher end of the distribution. Again, 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 2 950 tCO2e, or €10 600. This goes up to the very high estimate of the $\tau = 0.9$ quantile around €53 000. In fact

¹⁴Estimated using Stata ogln command by Williams (2010).

¹⁵Again, I multiply the unused credit entitlement by the 2012 price of €3.60 to convert it to lost profit.

the highest quantile estimates are not properly identified, because very few of the firms falling into these ranges are in the non-participating group.

τ	T^C	T^E
0.1	387.5	[-47, 495]
0.2	391.9*	[273, 949]
0.3	959.1***	[395, 987]
0.4	980.1***	[722, 1275]
0.5	947.9***	[824, 1297]
0.6	1 265.4***	[936, 1465]
0.7	1 274.6***	[1229, 3491]
0.8	4 400.9***	[3354, 8774]
0.9	24 766.2***	[10470, 32503]

Significance and confidence intervals are determined by bootstrap (100 replications)

Table 4: Quantile estimates from the smoothed maximum score estimator

The quantile analysis reveals that the error distribution indeed seems skewed: while the difference between the median quantile and higher quantiles is quite small, there seem to be very large outliers driving the estimates of the lowest quantile. The overall fit is quite good if evaluated with the method outlined by Kordas (2006) (cf. Appendix on page 28). This is also visually represented on figure 12 which compares the estimated probability of participating in the offset market from the probit and quantile model to the observed frequencies at different entitlement magnitudes.

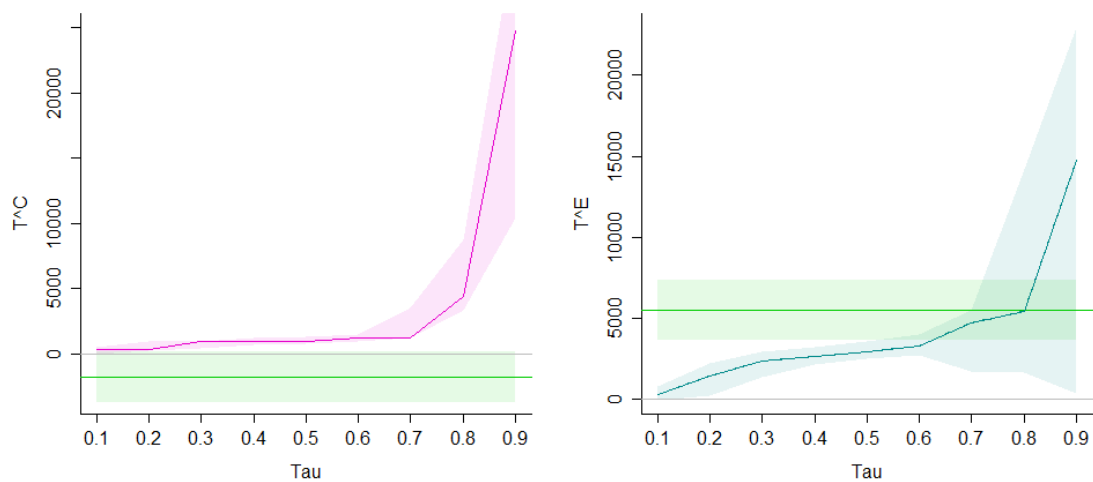


Figure 11: Estimated transaction cost - quantile plot

The dotted green line is the mean estimate from probit, the shaded bands represent the 95% confidence intervals.

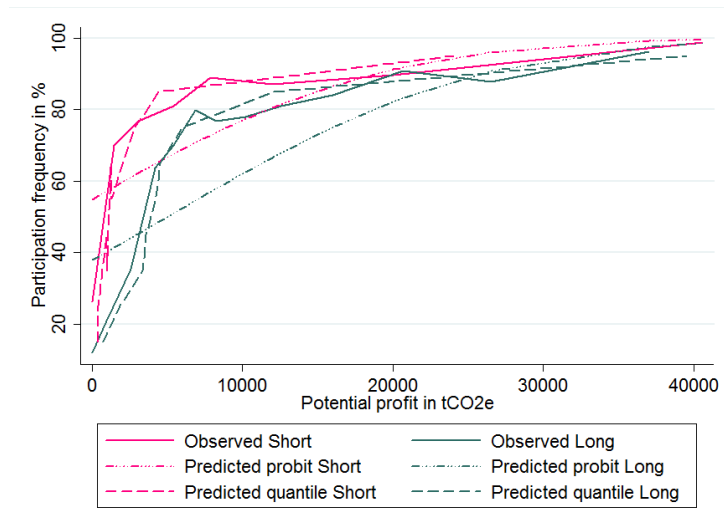


Figure 12: Observed frequencies and predicted probabilities of quantile method and probit (cut at 40 000 tCO₂e for better readability)

7 Concluding remarks

Within their obligations from the EU ETS, firms had the opportunity to reduce expenses by using their right to substitute “regular” certificates with international offset certificates. This study explains why the price of these international credits should always be inferior to the price of normal EU certificates. *A priori* it is thus always profitable to use offset certificates. However, many firms do not make full use of their offset entitlement.

Prior work has used survey data to show that compliance to the EU ETS generates managerial costs. To the best of my knowledge, this is the first study which establishes a framework to assess transaction costs empirically through the use of administrative data. These entry costs are estimated to be on average around €24 000 for general participation in the certificate market, be it EUA or CER certificates. However, this average hides a large heterogeneity that is best captured by a binary quantile estimation. Overall the empirical results underline that the behavior of the offset market is clearly impacted by initial allocation: it appears that transaction costs are mostly due to general participation in emission trading, rather than the offset market specific setup costs.

Environmental policy aims at reducing ecological harm at minimum cost to society. Most academic and policy-related work accounts only 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 too large to be ignored in policy discussion: policy makers tend to argue with results from the least-cost equilibrium in spite of the fact that this equilibrium cannot be reached in practice. 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 integrated 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 the European tendency to evolve towards more sophisticated (but complicated) policy designs. The problem is even more stringent if the costs impact firms differently, such as the ones estimated in this study.

Note that I only address part of the actually arising transaction costs: all costs that are unavoidable, such as monitoring and administration costs, do not affect behavior and can thus not be captured with my methodology. 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 in no way synonymous to the 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 CERs) caused

by transaction costs.

It remains to be analyzed, what exactly these costs include and how they could consequently be reduced to implement a less distortionary policy. In fact, this survey cannot differentiate between financial costs and more “behavioral” reasons, such as inattention, salience, risk aversion, misperceptions, etc. However, we are talking about the behavior of firms, so that psychological factors should play much less a role than they do for consumer decisions.

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A National offset entitlement rules

	Annual Cap (MMt CO2e)	Ph.II (%)	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 5: Offset limits collected from National Allocation Plans by Elsworth et al. (2012)

B Availability of offset certificates

All issued CERs have to be authorized and validated by UNEP Risoe, which establishes a central registry. It is difficult though to determine the number of CERs available for compliance in the EU ETS, as other sources for demand exist: mostly Appendix I countries needing to comply to their Kyoto obligations, but also other regional and voluntary emission trading schemes. The amount shown in figure 13 is technically thus an upper bound of the amount disposable for compliance in the EU ETS.

It has been argued that there has been a surplus of AAUs within in the Kyoto protocol framework. These certificates are traded infrequently and bilaterally, mostly directly between participating states, so that there is no clear 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)). In that case, Appendix I countries have little interest to comply to their Kyoto obligations using CERs, so that the total amount of CERs issued is likely to be a good approximation of the amount actually available to firms for compliance in the EU ETS.

Figure 13 shows that the amount of ERUs issued starts slowly but takes off in the last two years of phase II. Overall, there were enough offsets available to fully exploit potential profits from substitution of EUAs by CERs by the end of phase II. Although use rose sharply in the last year, it remained below the produced supply.

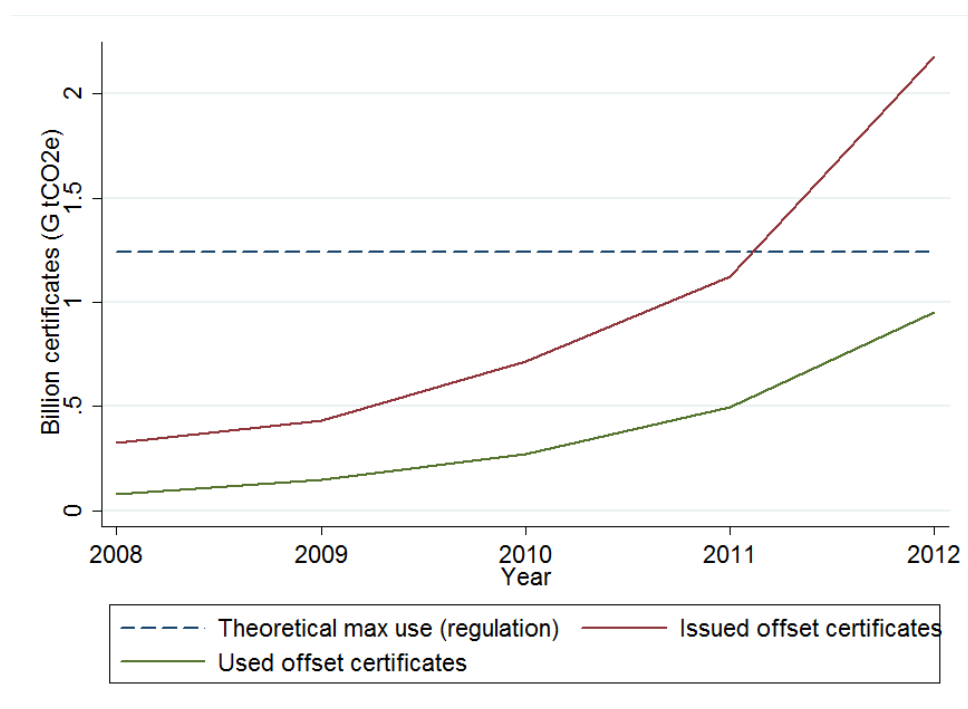


Figure 13: Availability of CERs and ERUs

Some CERs lost validity after compliance deadline of April 2013 because of quality concerns over their environmental integrity. Among canceled CERs were those generated through “industrial gas” methods which had constituted about 60% of the issued CERs. With their convertibility into EUAs these “gray” CERs as they are called now (in opposition to still valid “green” CERs) have lost virtually all their market value and traded at around 1 cent per ton after April 2013. Incentives have thus been particularly strong to submit or sell these certificates before the end of phase II.

C Level of analysis: firms or plants

All literature on the use of offset credits in the EU ETS looks at the time evolution of aggregated data, firm-specific behavior does not enter the picture.

The EU registry used for this paper is at the plant-year level. However, Jaraite et al. (2013) have matched plants to the companies which own them and many of these plants belong to the same firms. A “firm” is defined by ownership: the firm is defined an entity of which no other entity holds more than 50.01%. On average a firm owns 16 plants and the biggest firm in the sample holds 165 plants. As firms usually share many services across most/all of their plants, it would make sense to analyze behavior at this level. Indeed, table 6 shows that the large majority (71%) of plants belong to a firm that follows the same strategy.

	Installation strategies				Total
	1_Used none b	2_Used some b	3_Used all progressively b	4_Used all at once b	
1_Firm used none	160	0	0	0	160
2_Firm used some	491	992	1432	711	3626
3_Firm used all progressively	0	0	511	160	671
4_Firm used all at once	0	0	0	195	195
Total	651	992	1943	1066	4652

Table 6: Comparison of plants’ strategy and owning firm’s strategy (counts, only among firms with more than 1 plant)

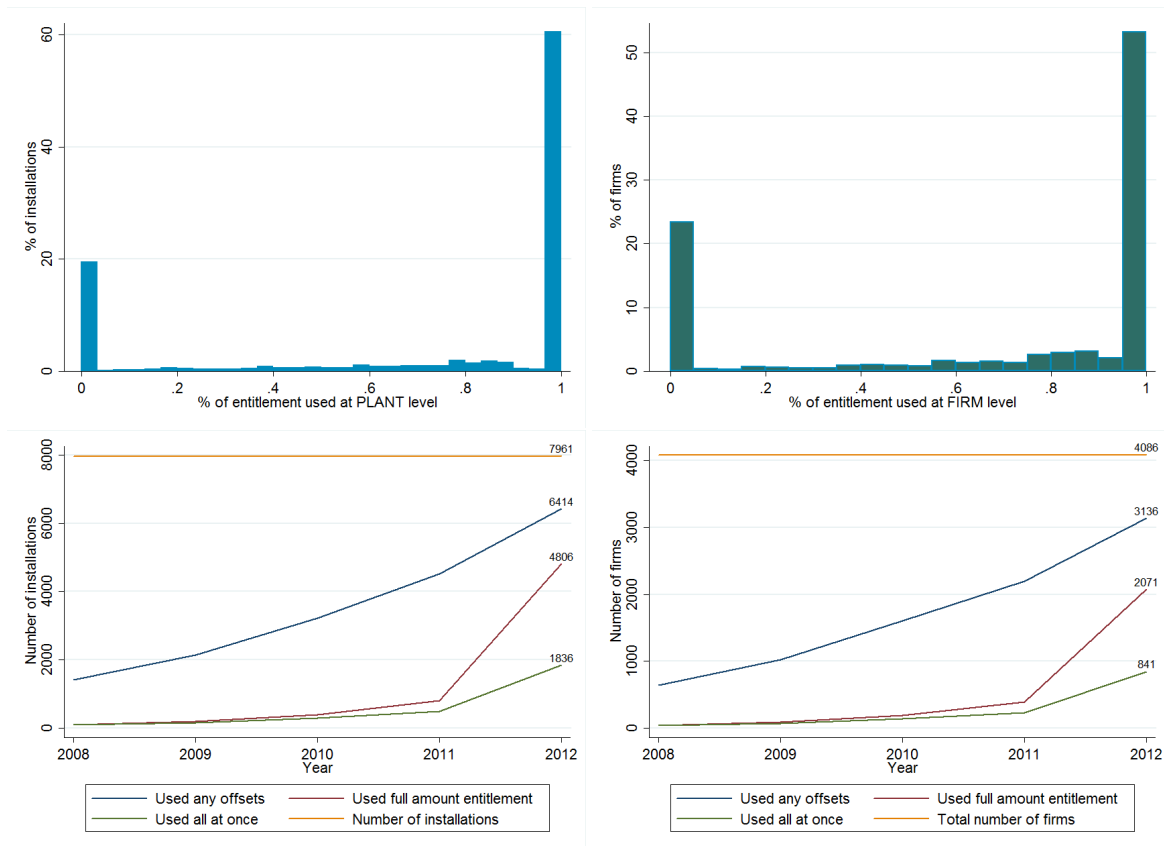


Figure 14: Utilization and timing of plants and of firms (source: EU CITL registry)

D Are emissions constrained by transaction costs?

In section 3.3, I claimed that transaction costs do not constrain emissions, although this was theoretically possible. Beyond the argument on the shape of the cost function (being relatively inflexible in substituting emissions) and the relatively low importance of the cost factor emission compliance, I argued that there is no crowding of emissions at the level of allocations. Figure 15 shows the ratio of emissions to allocations; crowding of emissions at allocation would mean that there would be a spike where this ratio is equal to 1.

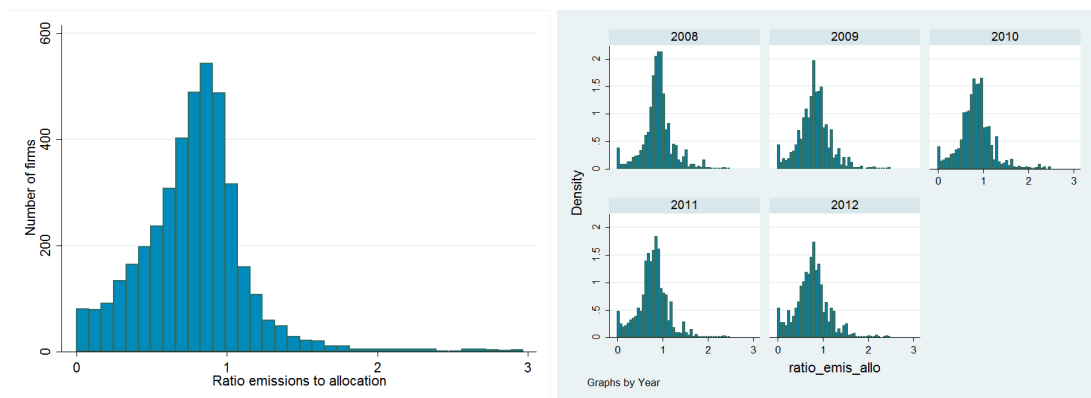


Figure 15: Ratio of emissions to allocations

E Quantile regression fit

Kordas (2006) suggests to verify the fit of the quantile regressions by predicting probabilities for each observation and verifying that each 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:

$$\hat{\tau}_i = \operatorname{argmin}\{\tau : K_i - T^C - \mathbb{1}_i^{\text{long}} T^E \geq 0\} \quad (28)$$

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

$$\hat{P}_i = (1 - \hat{\tau}_i, 1 - \hat{\tau}_{i,-1}) \quad (29)$$

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 7. Except for the lowest quantile, the models seem to fit the data reasonably well.

Predicted probability	10%	20%	30%	40%	50%	60%	70%	80%	90%
Observed frequency	12.0%	16.0%	32.5%	32.9%	50.9%	68.0%	72.3%	79.5%	94.5%
Number of observations	125	238	114	73	57	178	483	943	1876

Table 7: Specification test of binary regression quantile models