Discussion Paper No. 12-021

Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme

Peter Heindl

Zentrum für Europäische
Wirtschaftsforschung GmbH

Centre for European
Economic Research

Discussion Paper No. 12-021

Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme

Peter Heindl

Non-Technical Summary

In this paper, transaction costs of German firms, regulated under the EU emissions trading scheme (EU ETS) are examined empirically. Introduced in 2005, the EU ETS currently regulates carbon dioxide emissions of roughly 11,000 installations in the 27 EU member states, Norway, Liechtenstein and Iceland. Its aim is to reduce greenhouse gas (GHG) emissions in energy intensive industry branches and utility companies by 21 percent until 2020 compared to 2005.

Transaction costs can be seen as costs for managing the EU ETS and carrying out necessary administrative tasks. As the data reveal, transaction costs depend on annual emissions and annual volumes of traded emissions allowances of firms in a non-linear fashion, based on OLS and nonparametric estimation. This implies the presence of scale economies in the management of the EU ETS. Overall transaction costs increase for firms that have emissions levels ranging from zero to approximately one million tons of CO_2 emissions per year. Overall transaction costs decrease for firms with more than one million tons of CO_2 emissions (see figure 3). Based on the results, overall annual transaction costs for all German firms regulated under the EU ETS are estimated at 8.7 EUR million c.p. in average.

In contrast to assumptions made by standard economic theory, marginal transaction costs also depend on annual emissions levels and annual trading volumes respectively. This implies that firms also take the costs of managing the EU ETS and costs for general administrative obligations into account when minimizing costs under the EU ETS. As a consequence, the firm's incentives for greenhouse gas abatement are different than in a 'first-best' case with zero transaction costs. In practice, firms with less than one million tons of annual emissions (which do not profit from economies of scale in the management) will emit less (abate more) than emitters with more than one million tons of annual emissions. Although the changes are small and will not affect environmental effectiveness of the EU ETS, economic efficiency is decreased by transaction costs, resulting in a welfare loss.

The average transaction costs (transaction costs divided by annual emissions) are highly different for firms of different sizes. Average transaction costs are relatively high for smaller emitters (up to EUR 1.00 per ton CO_2), but trickle down with rising annual emissions of a firm. At low emissions levels, such as 5,000 or 10,000 tCO_2 p.a., doubling emissions leads to a reduction of average transaction costs by almost 50 percent (see figure 2).

Das Wichtigste in Kürze

In diesem Arbeitspapier werden Transaktionskosten deutscher Unternehmen im EU Emissionshandel (EU EHS) empirisch untersucht. Seit 2005 werden im EU EHS die CO_2 Emissionen von etwa 11.000 Anlagen in den 27 EU Mitgliedsländern, Norwegen, Lichtenstein und Island reguliert. Ziel ist es bis 2020 eine Reduktion des Treibhausgasausstoßes um 21 Prozent im Vergleich zu 2005 zu erreichen.

Transaktionskosten können als Kosten gesehen werden, die beim Management und anderer administrativer Aufgaben durch das EU EHS in regulierten Unternehmen entstehen. Wie die Daten zeigen, sind diese Kosten in nicht-linearer Weise abhängig von den jährlichen Emissionen und Handelsmengen an Emissionsrechten eines Unternehmens, basierend auf OLS und nichtparametrischen Schätzmethoden. Dies bedeutet, dass Größenvorteile beim Management des EU EHS bestehen dürften. Die gesamten Transaktionskosten nehmen bis zu einer Emissionsmenge von etwa 1.000 $KtCO_2$ pro Jahr stetig zu, nehmen jedoch ab mit Emissionsmengen größer als 1.000 $KtCO_2$ (siehe Grafik 3). Basierend auf den Ergebnissen der Schätzung dürften die gesamten jährlichen Transaktionskosten, die Unternehmen in Deutschland durch das EU EHS entstehen, bei im Durchschnitt c.p. gut 8,7 Millionen EUR liegen.

Entgegen üblicher theoretischer Annahmen sind die Grenztransaktionskosten, also die zusätzlichen Transaktionskosten, die durch die Emission einer zusätzlichen Einheit Treibhausgas entstehen, ebenfalls von jährlichen Emissionen und Handelsmengen abhängig. Dies bedeutet, dass Unternehmen bei der Entscheidung über kostenminimierende Emissionsmengen auch die Transaktionskosten in Betracht ziehen. Dadurch unterscheiden sich die optimalen Emissionsmengen in der Praxis von den in der Theorie angenommenen optimalen Mengen ohne Transaktionskosten. Unternehmen mit weniger als 1.000 $KtCO_2$-Emissionen pro Jahr emittieren weniger (vermeiden mehr) als ohne Transaktionskosten erwartet. Auch wenn die Veränderungen im Vergleich zur Situation ohne Transaktionskosten vergleichsweise klein sind und die ökologische Effektivität des Instruments nicht in Frage stellen, so kommt es doch zu Verlusten ökonomischer Effizienz und daher zu Wohlfahrtsverlusten.

Durchschnittliche Transaktionskosten (Transaktionskosten dividiert durch jährl. Emissionsmenge) unterscheiden sich stark zwischen Unternehmen unterschiedlicher Größe. Durchschnittliche Transaktionskosten sind sehr hoch für kleine Emittenten (bis zu 1,00 EUR pro tCO_2), fallen aber schnell mit steigender Emissionsmenge. Bei geringen Emissionsmengen, etwa 5 oder 10 $KtCO_2$, führt eine Verdopplung der Emissionen zu einer Verminderung der durchschnittlichen Transaktionskosten von fast 50 Prozent (siehe Grafik 2).

Transaction Costs and Tradable Permits

Empirical Evidence from the EU Emissions Trading Scheme

Peter Heindl*

March 2012

Abstract

In this paper, transaction costs in the EU emissions trading scheme (EU ETS) are examined empirically based on survey data from German companies. Transaction costs from measurement, reporting and verification (MRV) of emissions, permit trading and general informational costs are considered. Transaction costs from MRV and permit trading are of non-linear form and dependent on annual emission and trading volumes based on OLS and non-parametric estimation. As a consequence of non-linear transaction costs, welfare losses occur compared to a first-best setup under zero transaction costs. In practice, smaller emitters will emit less (abate more) compared to larger emitters and vice versa due to economies of scale in the management of emissions trading. The results further imply that optimal firm size might be influenced by transaction costs in the EU ETS because of relatively high average transaction costs amongst smaller emitters. Overall annual transaction costs in the EU ETS in Germany are estimated to be EUR 8.7 million.

JEL-Classifications: Q52; H23; D23

Keywords: Emissions Trading; Transaction Costs; EU ETS

---

* Centre for European Economic Research (ZEW), Department of Environmental and Resource Economics, Environmental Management, L7, 1 – D-68161 Mannheim, Germany. E-mail: heindl@zew.de

I would like to thank Benjamin Lutz (Centre for European Economic Research, Mannheim), Daniel Osberghaus (Centre for European Economic Research, Mannheim), Wolfgang Buchholz (University of Regensburg), Ebru Voyvoda (Middle East Technical University, Ankara) and Fabian Joas (PIK Potsdam) for useful comments and discussions and Karl Ludwig Brockmann (KfW Bankengruppe), Vivien Lo (KfW Bankengruppe), Andreas Löschel (Centre for European Economic Research and University of Heidelberg) and Jan Schumacher (KfW Bankengruppe) for promoting this research.

1. Introduction

Since long there has been a discussion in the economic literature about 'frictions', which are effects that hamper or at least influence economic activities and do not fit into existing theory. Hicks (1935) called for a more precise definition of 'frictions' and was the first who interpreted frictions as costs (Klaes, 2000). Although Coase (1937) related the existence of firms to their capability to facilitate certain transactions more efficiently and less costly than it would be the case on the open market, he did not use the phrase 'transaction costs' at all. In contrast, costs of transacting played a prominent role in monetary theory and literature on financial markets in the 1950s and 1960s[1]. In the 1970s a branch of economic literature evolved, labeled 'economics of organization'. Probably one of the most prominent early contributions in the field was made by Williamson (1971). By putting in focus possible market failures and organizational response to those 'frictions', a new field of research evolved, which still is growing.

From the perspective of public and welfare economics, transaction costs might be of interest in two aspects. First, because transaction costs might lead to unexpected 'frictions', e.g. under environmental regulation, and thus cause welfare losses compared to a first-best world with zero transaction costs[2]. This neoclassical notion of transaction costs is widely accepted and policy-evaluations often aim to account for market failure, including the consequences of transaction costs. A second aspect, however, seems to be omitted in the current literature on transaction costs under environmental regulation. Namely, that not only economic agents react to 'frictions' so that welfare losses might occur, but also organizations, such as firms, adapt to those 'frictions', consequently changing the overall market structure (Solomon, 1999).

Given the growing popularity of quantity regulation in climate policy, organizational response to policy induced 'frictions' beyond aspects like carbon leakage etc. is by no means trivial. If, for example, transaction costs from environmental regulation are non-linear, alter the marginal condition for cost-minimization of firms and have a more severe impact on smaller firms or emitters compared to larger ones, then those policy induced 'frictions' could lead to larger optimal firm-size or larger optimal size of regulated sources of emissions in equilibrium. Consequently, it could also represent a barrier for incumbents to enter the market. Both effects could have negative impacts on the economy by fostering market concentration and weakening competition.

The aim of this paper is to analyze the impact of transaction costs on firms under quantity regulation based on the example of the European emissions trading scheme (EU ETS). Special attention will be paid to the functional form of transaction costs, e.g. if they are of non-linear structure, which would imply economies of scale in the management of the EU ETS on the firm level and could induce efficiency losses (Hanemann, 2009). This paper analyses transaction costs under given regulation, also implying under given externalities that stem from preexisting transaction costs which prevent proper internalization (Coase, 1960; Dahlman, 1979).

---

[1] Costs for transacting motivated inter alia the contributions of Marschak (1950), Baumol (1952) and Tobin (1956) and authors from theoretical or mathematical economics, such as Foley (1970). As summarized by Klaes (2000) this 'neoclassical' branch of literature is frequently omitted in the discussion on transaction costs. In fact, the existing body of literature on transaction costs is large. See Allen (2000) for an extensive summary.

[2] It has to be noted that the existence of externalities, and hence, the need for regulation is expected to stem from the existence of transaction costs. If the costs of transacting and setting up contracts would be zero, possible Pareto improvements could be realized by bargaining of self-interested economic agents (Coase, 1960; Dahlman, 1979).

Consequently, transaction costs, e.g. in a scheme of tradable permits, represent a second-moment of the costs of transacting and can be expected to generate externalities themselves. This also implies that if transaction costs are present under regulation, it will fail to fully internalize market distortions.

The paper is organized as follows: section 2 provides an overview of the EU ETS and aims to highlight possible sources of transaction costs under the current design of the trading scheme. The general discussion on transaction costs and tradable permits is wrapped up in Section 3. The section also provides a brief expansion of existing approaches to transaction costs to the EU ETS. Based on firm-level data from Germany, which are described in Section 4, the impact of transaction costs on regulated firms is examined empirically in Section 5. The empirical results and their implication for theory and practice are discussed in Section 6 and section 7 provides a short conclusion.

2. The EU ETS in Practice

Introduced in 2005, the EU ETS currently regulates carbon dioxide emissions of roughly 11,000 installations in the 27 EU member states, Norway, Liechtenstein and Iceland. Its aim is to reduce greenhouse gas (GHG) emissions in energy intensive industry branches and utility companies by 21 percent until 2020 compared to 2005. The first three years (2005 to 2007) served as a trial phase, characterized by economy-wide over-allocation of freely distributed permits. EU member states were obligated to distribute at least 95 percent of permits for free. With the start of the Kyoto commitment period in 2008, the second trading phase of the EU ETS started. In 2008, the overall cap on emissions was decreased. Member states were expected to distribute at least 90 percent of permits for free in the second trading period (2008 to 2012). While the annual installation specific free allocation is fixed over the second trading period, output and emissions depend on overall economic conditions. In the course of the economic downturn of the years 2008 and 2009, overall emissions dropped, resulting in a large amount of surplus allowances. In 2008, 69 percent of installations in the EU ETS had received over-allocation.

Given the high share of installation specific over-allocation and options for intra-firm permit exchange in firms with more than one regulated installation (about 30% of firms in Germany), purchasing of EU emissions allowances was not necessary for most firms. In Germany, for example, trading activities in 2009 and 2010 were modest. About half of the firms participated in the market for EU allowances in 2009 and 2010. Less than 20 percent of firms traded more than once per annum. Frequent trades, e.g. daily or weekly, are conducted mostly by very large emitters (Löschel et al., 2010, 2011). This implies that many over-allocated firms choose to bank allowances[3] or occasionally sell smaller amounts of permits to the market. Trading of allowances occurs to a high extent bilaterally or with the help of intermediaries, such as Banks. Larger emitters that purchase or sell relatively high amounts of permits each year tend to trade directly at exchanges. Since there are a number of intermediaries in the market for EU emissions allowances and there are liquid exchanges, finding a buyer/seller and negotiating prices and quantities is not

[3] Banking of allowances refers to the case when firms hold back allowances allocated or purchased in period t_1 for compliance in period t_2 or later. In the EU ETS, full banking of EU allowances is permitted in the period 2008 to 2020. Banking increases flexibility in a scheme of tradable permits and fosters intertemporal economic efficiency. For a detailed discussion on banking see Tietenberg (2006).

a problem. In this aspect the EU ETS strongly differs from trading schemes established under Title IV of the Clean Air Act where trading of permits was associated with high transaction costs (Hahn & Hester, 1989).

One of the most important sources of transaction costs in the EU ETS currently are obligations from monitoring, reporting, and verification (MRV) as reported by Jaraitė, Convery & Di Maria (2010) for Ireland and Löschel et al. (2010, 2011) for Germany. Firms are obligated to measure or calculate emissions. This process is time demanding because data on emissions have to be collected on the installation level and have to be analyzed for emissions reporting each year. Emissions data must be verified by a certified and independent third party, which generates costs. Finally, the data have to be reported to the national authorities in a standardized form, which again is time demanding. The annual MRV process is obligatory for all regulated firms in the EU ETS.

Also costs from application for free allocation are present in the EU ETS. The amount of freely allocated permits is determined for each installation separately and for each trading period. For the third trading period of the EU ETS from 2013 to 2020, highly specific allocation rules were defined by the EU commission. Allocation will be based on product benchmarks for industrial installations. While there will be no free allocation for power generation from 2013 onwards, heat generation (often a by-product of power generation) will still be supplied with free allocation. Although the application process for free allocation is time demanding and costly, firms will receive indirect subsidies via freely allocated permits after application with a high probability. Consequently, costs from applying for free allocation cannot be regarded as pure transaction costs. In contrast, they can be regarded as an investment in a project with high probability of yielding a positive return. Costs from plying for free allocation are therefore not examined in this paper.

Firms might face transaction costs, or more precise, informational costs when searching for appropriate technology for abatement and general information which is relevant for planning optimal abatement strategies. From 2005 to 2010, 64 percent of German firms in the EU ETS have scheduled abatement measures, mostly measures to increase energy efficiency. Based on the average lifecycle of existing machinery, larger volumes of GHG abatement will likely be achieved through reinvestment and replacement of existing machinery from 2020 to 2030 (Löschel et al., 2010, 2011). While emissions trading is in general expected to incentivize innovation for pollution abatement in an efficient way (Downing & White, 1986; Milliman & Prince, 1989), innovations might occur inside as well as outside regulated companies. Especially smaller emitters might buy abatement technology on the market rather than innovate themselves. Also mixed innovation processes might occur where abatement technology is partly purchased externally and partly redesigned or enhanced internally based on specific needs for production. In any case, costs for transacting on markets for abatement technology and gathering information inside and outside the firm might occur. To control for informational costs related to abatement and innovation, these costs are treated separately in the empirical analysis.

A special characteristic of the EU ETS is the highly uneven distribution of annual emissions volumes. In Germany, more than 50 percent of regulated firms emit less than 25,000 t CO_2 per year. In contrast, there are few large emitters with annual emissions up to roughly 100 million tons CO_2 per year. 90 percent of emissions in the EU ETS in Germany stem from 10 percent of firms. This highly uneven distribution might also impact management strategies. While large emitters can be expected to manage tasks like trading of permits highly professional, smaller emitters will likely spend much less effort, given the smaller value at stake. Transaction costs might well explain management strategies in the EU ETS. On the other hand, the uneven distribution of annual emissions and differing management practices might explain observed patterns of transaction costs.

3. Transaction Costs and Tradable Permits

The most important contributions regarding transaction costs in schemes of tradable permits stem from Stavins (1995) and Montero (1998). As summarized by Hanemann (2009) both articles refer to transaction costs that arise from permit exchange amongst firms. Montero (1998) suggests: *"Provided that agents willing to trade have to enter the market, find one another, communicate (negotiate price and quantity), and sign the corresponding legal contract, some level of transaction costs is always likely to exist – as in any market transaction".* Since every transaction incurs a contract, transaction costs are highly dependent on the requirements for finalizing a contract. As Hahn & Hester (1989) report, finding a potential seller for permits and obtaining regulatory approval for a trade was rather costly in trading programs established under Title IV of the Clean Air Act in the United States. In contrast, exchange of permits is uncomplicated in the EU ETS since there are liquid exchanges for EU emissions allowances and regulatory requirements for exchanging permits are low[4].

One of the most interesting findings by Stavins (1995) probably is, that if there are transaction costs that enter in a non-linear fashion into the cost function, the optimal amount of emissions under regulation e_{TC}^* is no longer independent of initial free allocation received by a firm, which also implies that actual emissions levels under transaction costs differ from first-best emissions levels $e_{TC,i}^* \neq e_i^*$. Consequently, also the permit price in equilibrium differs in a setup with and without transaction costs[5]. The result is of interest in principle as well as in practice. First, because it augments the analysis of efficiency of allocation under emissions trading by Montgomery (1972) and, second, because it highlights the importance of transaction costs in applied environmental policy, especially for the design of market based programs where additional transaction costs arise from permit trading. In fact, transaction costs could lead to a situation where marginal abatement costs are not equated amongst all regulated sources of emissions which would result in a loss of economic efficiency (Baumol & Oates, 1971).

Beside transaction costs that arise from permit exchange between regulated emitters, three additional sources of transaction costs in regulated firms are possible. First, transaction costs that stem from the application for free allocation at public authorities. Second, transaction costs that stem from compliance, e.g. measurement, reporting and verification of emissions. And third, transaction costs that stem from the examination of abatement costs when several abatement technologies can be considered and the related costs or quantities of abatement are uncertain

[4] The exchange simply has to be reported to the central permit registry for clearing. Current prices can be obtained at exchanges and might be a reference also for bilateral permit exchange.

[5] The theory has been examined in an experimental setup by Cason & Gangadharan (2003). The experimental results give support to the theoretical analysis.

(Crals & Vereeck, 2005). In sum, all kinds of transaction costs mentioned so far can be regarded as costs that stem from management and compliance under a scheme of tradable permits[6]. Firms are free to choose an individual amount of effort to spend on the different tasks as long as minimal requirements for compliance are met.

Starting from the standard cost-minimization problem under regulation by tradable permits, the four possible sources of transactions costs can be illustrated easily. As proposed by Baumol & Oates (1971) and Montgomery (1972) firms are expected to minimize costs under regulation. Costs for a single firm depend on individual abatement costs $c(e) \geq 0$, the exogenous permit price $p \geq 0$ and emissions $e \geq 0$. The firm faces the problem

$$\min_{e} \; [c(e) + p \cdot e]. \tag{1}$$

Deriving by e yields the cost-minimizing level of emissions e^* where the permit price equals marginal abatement costs

$$-\,c'(e) = p. \tag{2}$$

Now, several kinds of transaction costs can be introduced. Overall emissions e are decomposed by $e = a + u$, where a is the free allocation received by the firm with $a \geq 0$ and u is the amount of permits that must be purchased for compliance or can be sold due to over-allocation.

a) Transaction costs in permit trading

In the case of permit trading and the presence of free allocation, $p \cdot e$ in equation (1) becomes $p(a + u)$. If trading of permits is associated with transaction costs dependent on the amount of traded permits $f(u)$[7], the corresponding condition for minimizing costs and the marginal condition are

$$\min_{e} \; [c(e) + pe + f(e - a)] \tag{3}$$

$$-\,c'(e) = p + f'(e - a). \tag{4}$$

b) Transaction costs in the application for free allocation

Firms might face a costly and time demanding procedure of application for free allocation. Costs of that kind are present in the EU ETS where application for the third trading period (2012 to 2020) is dependent on highly specific product benchmarks. Firms can be assumed to face fixed costs in application independent of their emissions-level. Also, scale-effects might occur in the process of application, leading to non-linear costs. However, since firms that apply for free allocation basically apply for a subsidy on a voluntary basis, the process of application could be seen as a highly promising lottery or a project with a very high probability of yielding positive

[6] This definition of transaction costs is in accord with the definition made by Dahlman (1979). Possible sources of transaction costs under environmental regulation are summarized in detail by Crals & Vereeck (2005).

[7] Since each transaction might be associated with utility, the transaction cost functions $f(u)$, $g(e)$ and $h(e)$ can be interpreted as 'production functions' for transaction. While the utility or service generated by $f(u)$, $g(e)$ and $h(e)$ is unobserved, it is implicitly assumed that firms choose the optimal amount of transactions and consequently aim to minimize transaction costs given their specific needs. This also implies that observed transaction costs are optimal transaction costs in equilibrium.

returns. With regard to this, costs of applying for free allocation are not considered as pure costs of transacting.

c) Transaction costs for compliance (monitoring, reporting, and verification)

In the MRV process which is necessary for compliance in the EU ETS, firms might be confronted with considerable costs. These costs are likely to be dependent on emissions-levels with relatively high fixed costs and resulting scale economies in MRV activities. MRV costs would come on top, entering the cost function in an additive manner. Although MRV costs are not directly related to transactions, they are necessary for defining property rights and hence to facilitate transactions. Given the MRV transaction costs term $g(e) \geq 0$, the cost function would modify to

$$\min_{e} \ [c(e) + pe + g(e)]. \tag{5}$$

The corresponding marginal condition is

$$-c'(e) = p + g'(e). \tag{6}$$

d) Transaction costs from examining abatement costs

When the assumption of full information of firms is relaxed and abatement occurs in a non-trivial technical way, firms might face costs for examining options for abatement and the related costs. While Downing & White (1986) showed that tradable permits are able to foster the introduction of cleaner technologies in production, the assessment of options to do so might be costly, representing possible transaction costs. Just as before those costs, denoted as $h(e) \geq 0$, might come on top of overall costs from regulation, yielding the problem

$$\min_{e} \ [c(e) + pe + h(e)]. \tag{7}$$

The marginal condition becomes

$$-c'(e) = p + h'(e). \tag{8}$$

Overall, there are four possible sources of transaction costs that have to be considered when examining environmental regulation by tradable permits. While cases a) and b) are limited to regulation by tradable permits, cases c) and d) also occur under environmental taxes, with their extent depending on the design of the regulatory scheme (Crals & Vereeck, 2005). Although the effects of transaction costs on economic efficiency are of general theoretical interest, the extent to which they occur in detail is of great importance when a trading scheme is examined empirically. This is because resulting welfare losses are expected to be dependent on the extent of the costs for transacting.

4. Data Description

The data used for estimation contains 150 observations and stems from two surveys amongst German companies regulated by the EU ETS. The data were gathered via an online-based survey in March 2010 and March 2011 and pooled for regression. Transaction costs were collected by asking survey participants about annual costs for the administration of the EU ETS. Transaction costs are divided in three subgroups. Costs for monitoring, reporting and verification (TCMRV) are the most important costs with a share of 69 percent of overall transaction costs in the sample. Administrative costs for permit trading (TCT)[8] which account for 19.57 percent of overall transaction costs. Other costs, such as informational costs for abatement and general strategy building (TCINFO) account for 11.43 percent of transaction costs. The sum of all three categories yields overall transaction costs (OTC).

When transaction costs were collected, survey participants were asked to put in the sum of days per year spent by employees for carrying out the tasks and the costs for external services and other expenditures in EUR separately. Days were translated into EUR by multiplying one day by eight hours and the average hourly costs for labor in the private sector in Germany which is determined to be EUR 30.90 in 2009[9]. Costs from the 2010 survey were inflated to the EUR 2011 level based on the official inflation rate of 2010 which was determined at 1.1 percent. Consequently, as far as costs in EUR are addressed in this paper, they shall be interpreted in EUR 2011.

For the analysis, 17 observations had to be dropped (not included in n=150). Four emitters were excluded because of extremely large emissions which are highly influential observations and have a negative impact on robustness. The largest emitter in the sample emits 1.9 million tons of CO_2 per annum. Emissions of the four dropped large emitters range from 4.4 to 102 million tons per annum. In general, annual emissions are distributed highly uneven amongst firms. In median, firms in Germany emitted about 25,000 tons in 2011. The largest emitter in the sample is close to the 95% percentile of the population, which is 1.9 million tons. At the 99% percentile in 2011, emissions are 8.6 million tons. This implies that the EU ETS is dominated by few very large emitters and a larger number of smaller emitters. For illustration, the Gini-coefficient over emissions in 2011 is 0.946, implying that more than 90 percent of annual emissions in Germany stem from less than 10 percent of regulated firms. Moreover, since large emitters are usually large firms in terms of operated installations and employees, surveyed persons from larger firms might find it hard to report on the whole company. Consequently, dropping large emitters from the sample increases robustness and credibility of data. Another 13 observations had to be dropped due to obvious errors from putting in data. As added-variable plots and a closer inspection of the observations revealed, surveyed persons seemed to have reported costs in EUR instead of workdays, resulting in massive outliers. Consequently, those observations are dropped from the sample for precaution, resulting in an overall number of n=150 observations appropriate for estimation.

A set of independent variables is available for estimation. Actual emissions of firms (VEREM), which are officially verified emissions, are measured in thousand tons of annual CO_2 emissions.

[8] TCT include costs for gathering information about market conditions and costs for risk management and excluding permit costs $p \cdot u$. Permit costs do not represent transaction costs, but are purely 'regulation costs'.
[9] Information on average hourly labor costs was derived from the German census bureau (*Statistisches Bundesamt*).

By using the number of freely allocated permits (ALDI, measured in thousand tons), theoretical trading volumes are derived by subtracting allocation from verified emissions. Resulting trading volumes (TVOLUME, measured in thousand tons) are defined as positive numbers, implying that selling or purchasing of permits is treated equally[10]. An extra dummy (DSELL) controls for net sellers and net buyers of allowances. INSTNR is the number of installations operated by a firm, DCOMB indicates if combustion installations dominate the portfolio of installations. DINDUS is a dummy for industrial facilities (others than utility companies). The number of employees is captured by the dummies D250 (250 to 1000 employees) and D1000 (more than 1000 employees). The corresponding reference category are small and medium sized companies (0 to 249 employees). DTRADE is a dummy that indicates whether a firm actually traded allowances while DTRADEMORE indicates that firms traded more than once per year. DMIT is a dummy that equals unity if abatement measures were taken since 2005, DASSESS indicates that a firm examined internal abatement costs and DINFO is a dummy that indicates a high degree of information about conditions in the permit market. Finally, D2TIMES is a dummy that identifies firms which have participated repeatedly in the survey.

Table 1: Summary statistics of variables used for estimation

Variable	Obs	Mean	Std. Dev.	Min	Max
otc	150	12223.64	16763.12	991.8	119552
tcmrv	150	8433.902	9008.551	495.4	71800
tct	77	4659.345	13856.82	101.1	102349.6
tcinfo	50	4193.832	5959.694	247.2	27774.19
verem	150	187.0267	361.2069	0	1918.189
tvolume	150	56.18635	126.1769	.0110016	1015.742
aldi	150	233.8277	451.6961	.147	2933.931
instnr	150	2.22	2.592892	1	14
dcomb	150	.72	.4505031	0	1
dindus	150	.5666667	.4971957	0	1
d250	150	.42	.495212	0	1
d1000	150	.1666667	.3739265	0	1
dtrade	142	.528169	.500973	0	1
dtrademore	142	.1760563	.3822163	0	1
dsell	150	.8733333	.3337134	0	1
dmit	149	.6375839	.4823194	0	1
dassess	143	.3496503	.4785356	0	1
dinfo	145	.2827586	.4519011	0	1
d2times	150	.48	.5012735	0	1

The variables VEREM, ALDI, TVOLUME, INSTNR, DSELL and DCOMB stem from the official EU ETS database of the European Commission (Community Independent Transaction Log). The remaining variables stem from the two surveys carried out in March 2010 and March 2011. As table 1 shows, the number of observations for TCT and TCINFO is lower than n=150, implying that those costs occurred only for some of the firms in the sample. Dummies are indicated by the prefix 'D' for convenience.

[10] Since actual trading volumes are private information and only a dummy variable is available that indicates if a firm actually traded, 'theoretical trading volumes' are used as a proxy for the number of permits that could be traded, indicating the 'value at stake' for each individual firm. The higher the difference between freely allocated permits and additional needed or surplus permits, the more effort a firm might spent on trading or considering trades.

5. Empirical Model, Estimation and Estimation Results

To estimate the extent to which transaction costs occur and to identify firm characteristics that influence those costs, data on overall transaction costs (OTC), costs for MRV (TCMRV), permit trading (TCT), and informational costs (TCINFO), as described in chapter 4, are used for pooled regression. As argued in section 3, overall emissions level e_i of firm i are expected to be the most important driver of transaction costs for MRV and information gathering. In the case of transaction costs that stem from permit trading, theoretical trading volumes $u_i = |e_i - a_i|$ are used for regression. Abatement costs $c(e)$ are private information and only actual transaction costs are observed. Therefore estimation takes place in a 'reduced form' manner. Since the aim of this paper is to analyze the structure of transaction costs in the EU ETS and extent to which they occur, a reduced form can be estimated without loss of information. The general empirical models are given by:

For overall transaction costs (OTC) and cases c) MRV (TCMRV) and d) informational costs (TCINFO)

$$\log(trc_i) = \beta_1 + \beta_2 e_i + \beta_3 X_i + \gamma_i. \quad (9)$$

Where e_i are annual emissions under the EU ETS, X_i is a matrix containing alternative firm characteristics which serve as control variables and γ_i is an error term which is normally distributed $N \sim (0, \sigma)$.

For case a) trading of allowances (TCT) the empirical specification is

$$\log(tct_i) = \alpha_1 + \alpha_2 u_i + \alpha_3 X_i + \alpha_4 Z_i + v_i. \quad (10)$$

Where u_i are theoretical trading volumes, X_i is a set of firm characteristics, Z_i is a set of characteristics that relates to trading activities of firm i and v_i is an error term, distributed $N \sim (0, \sigma)$.

Probably the most interesting aspect of the analysis is the parameterization of the empirical model. In practice, this implies to test linear specifications as in (9) and (10) versus alternative specifications that allow annual emissions e_i or trading volumes u_i to enter the regression in a non-linear way. The reason is that non-linear specifications would imply economies of scale, which are of great relevance for the evaluation of the impact of transaction costs in practice.

To test non-linearity, two different approaches are used. First, models (9) and (10) are estimated using OLS, including linear and non-linear parameterization for emissions e_i or theoretical trading volumes u_i. OLS models are compared based on model-fit, information criteria and the RESET test for model specification. Second, models are estimated using non-parametric methods. Non-parametric estimation does not require any specific parameterization of the empirical model and may therefore be able to capture possible non-linear effects more precisely than parametric OLS. In practice, (9) is tested against the alternative specification[11]

[11] It turned out that alternative specifications including e_i^3 or higher order cannot be applied to the dataset in a meaningful way and is therefore not further considered for the case of OLS estimation.

$$\log(trc_i) = \beta_1 + \beta_2 e_i + \beta_3 e_i^2 + \beta_4 X_i + \varepsilon_i. \tag{11}$$

In addition, results from the non-parametric estimation are contrasted to OLS results. The non-parametric estimation model as discussed by Li & Racine (2007) is of the general form

$$\log(trc_i) = g(e_i, X_i, \beta) + \theta_i. \tag{12}$$

The estimation procedure for the case of permit trading (10) is organized in the same manner.

5.1. OLS Estimation Results

Table 3 presents OLS estimation results. For all OLS estimations, robust standard errors were calculated since graphical and statistical tests indicated that there might be a heteroscedastic pattern in the data[12]. The first four columns of table 3 are estimation results with the log of overall transaction costs log(OTC) as dependent variable. Testing a linear (col. 1) vs. a quadratic parameterization (col. 2) shows that overall transaction costs are likely to be non-linear in the annual amount of emissions. Larger firms with more than 1000 employees (D1000) and firms that actually traded allowances (DTRADE) have higher fixed transaction costs compared to the reference case which is a small and medium sized company that did not trade permits. Surprisingly, firms that trade more than once per year (DTRADEMORE) exhibit lower absolute fixed transaction costs. This highlights that different sources of transaction costs, e.g. for MRV and trading, have to be examined separately.

Transaction costs for MRV are examined in columns (5) to (7) of table 3. Again, a quadratic parameterization (col. 6) seems to be appropriate for estimation based on general model fit and RESTET tests. Adding additional control variables that might be of relevance for MRV activities, such as employed technology and firm size does not significantly change overall estimation results. Moreover, none of the added variables is statistically different from zero. As a result, annual emissions seems to be the most important variable influencing transaction costs from MRV activities. The a priori expectation that combustion installations (DCOMB) might come along with differing transaction costs for MRV activities compared to other industrial installations was not confirmed. Although combustion installations show higher fixed transaction costs for MRV (0.149227), the effect cannot be considered as significantly different from zero. Also the number of installations operated by firms (INSTNR) and firm size (D250, D1000) have no statistically significant impact on transaction costs for MRV.

Transaction costs for trading of allowances or for considering trades (e.g. information gathering and observation of the market) are examined in columns (8) to (10) of table 3. Testing a linear vs. a quadratic parameterization shows that transaction costs for trading appear to be of linear form when estimated with OLS. This is in contrast to transaction costs for MRV. Firms face fixed costs for market participation. In addition each permit available for trading triggers additional transaction costs. Other effects, such as firm size (D250, D1000), trading frequency (DTRADE, DTRADEMORE) or whether a firm is net buyer or seller of permits (DSELL) show no significant effect.

[12] Residual-versus-fitted plots and Stata's Breusch-Pagan/Cook-Weisberg test for heteroscedasticity were used.

General informational costs, e.g. for emissions abatement or information on legal aspects, are examined in columns (11) to (13) of table 3. The available sample collapsed considerably in this case. For estimation, n=48 observations are available, compared to n=150 of the full sample. One likely reason is that many respondents felt unable to report on informational costs, either, because they did not occur or, because, they are difficult to measure as they are included in other tasks. Neither a linear parameterization (col. 11), nor a non-linear one (col. 12) was able to capture informational costs properly. The most promising approach was an OLS regression, including several dummies (col. 13). Information with regard to the market for allowances (DINFO) turned out to be of significant impact. As expected, firms that have a high amount of knowledge and information on the market for allowances have higher fixed informational costs (approx. EUR 2,270 p.a.) compared to firms with a relatively low degree of information. Also industrial installations (DINDUS), meaning firms other than utility companies, have slightly higher fixed informational costs in average (approx. EUR 1,040). This could give support to the thesis that more complex abatement technology is needed in industrial processes compared to utility companies. Informational costs are relatively low and not significantly different from zero for larger firms (D250, D1000), firms that have actually scheduled mitigation activities since 2005 (DMIT) or have examined abatement costs since 2005 (DASSESS).

Summarizing the results of the OLS estimations presented in table 3 it can be concluded that overall transaction costs under the EU ETS are of non-linear form based on survey data measuring transaction costs of 2009 and 2010. This implies that economies of scale in carrying out transactions under the EU ETS are present (please see also figure 3). MRV costs are currently the most important source of transaction costs occurring in all regulated firms. MRV costs are also the main driver of non-linear overall transaction costs in the EU ETS. Transaction costs for allowance trading are treated best in a linear way, rising in the amount of permits available to sell or be purchased. Informational costs seem to be pure fixed costs.

Since annual emissions (VEREM) could be endogenous, a simple Hausman test was applied. VEREM was regressed on the full set of control variables in eq. (4) of table 3 and additional explanatory variables (step one), residuals from this estimation were predicted, plugged in to the original equation (4), and estimated with OLS (step two) as proposed by Wooldridge (2002). Based on this procedure no evidence was found for VEREM to be endogenous since the fitted residuals in step two are not significantly different from zero, based on robust standard errors.

5.2. Non-parametric Estimation Results

To examine possible non-linear effects more closely, four non-parametric (NP) regressions are considered. The log of overall transaction costs log(OTC), costs for MRV log(TCMRV) and informational costs log(TCINFO) are examined dependent on annual emissions (VEREM). The log of transaction costs for permit trading log(TCT) is examined dependent on theoretical trading volumes (TVOLUME). Since the aim is to graphically compare OLS and NP regression (i.e. the sloping of the fitted regressions) and the influence of additional dummy variables is rather limited, no further variables are added to the NP regression.

Figure 3 shows the fitted values from OLS reference models and non-parametric estimation for the transaction cost categories considered. The figure on the upper left shows that, although quadratic OLS overestimates transaction costs for emission levels of 400,000 to 1,800,000 tCO_2 p.a. and underestimates for values > 1,800,000 tCO_2 p.a., quadratic OLS seems to be an appropriate parametric approximation. The upper right figure presents fitted values from OLS and non-parametric estimation for MRV transaction costs. The situation is almost the same as described before, implying that overall transaction costs are dominated by MRV transaction costs. For both cases transaction costs level-off for emission levels > 1,800,000 tCO_2. This indicates that transaction costs will, of course, not become negative with rising emission levels, but exhibit economies of scale. In both non-parametric regressions verified emissions turned out to be highly significant with a p-value of less than 1%. Corresponding R^2 values are 0.14 for overall transaction costs and 0.17 for MRV.

The lower left figure plots fitted values of OLS and non-parametric estimation for transaction costs from allowance trading. As non-parametric estimation implies, transaction costs from trading are highly overestimated by linear OLS while quadratic OLS underestimates for larger trading volumes. The figure casts doubt on the conclusion drawn from OLS model comparison discussed above. In fact, also transaction costs from allowance trading are likely to exhibit mild economies of scale, given that fitted values from NP estimation clearly show a non-linear pattern. In the NP estimation, the variable TVOLUME was significant on the five percent level (p-value 0.02005), the corresponding R^2 was 0.09.

Finally, fitted values for informational costs are plotted in the lower right figure. From OLS estimation, the first best model appeared to be set of dummy variables, implying that informational costs are independent of annual emissions. The figure compared quadratic OLS to NP estimation. Just as in the case of OLS, annual emissions turned out to be not significant in NP estimation. Consequently, it has to be concluded that annual emissions do not influence informational costs and that OLS including dummies only is an appropriate approach for estimation given the available data.

6. Discussion

From the results presented above two conclusions can be drawn. First, non-linear transaction costs are present in the EU ETS. The neoclassical notion of transaction costs imply that this will lead to efficiency losses compared to a first-best case, which is represented by Montgomery (1972) and the related literature. For illustration, model (2) of table 3 is estimated in levels. Estimation results of the simplified OLS model are presented in table 2.

Table 2: OLS Estimation of overall transaction costs dependent on emissions (thousand tons CO_2 p.a.)

β_2: emissions	48.78564 (3.01)***	**Model:** $otc = \beta_1 + \beta_2 verem_i + \beta_3 verem_i^2 + \varepsilon_i$
β_3: emissions^2	-0.0246899 (-2.92)***	t-values in brackets, R^2=0.1563, n=150,
β_1: _cons	7162.887 (6.47)***	F(2,147)=4.53, *** p-value<0.01

Under the assumption that overall transaction costs simply add up to costs under regulation, the marginal condition for minimizing costs including transaction costs for a single firm becomes c.p. in average

$$-c'(e) = p + 0.04878564 - 0.0000493798e. \quad (13)$$

Solving for p yields

$$p = -c'(e) - 0.04878564 + 0.0000493798e. \quad (14)$$

This effectively changes the perceived marginal costs of abatement and consequently alters the firm's optimal output of emissions. Given any specification of $c'(e)$ or any observed exogenous permit price p, the optimal emissions level in equilibrium will differ from the case of zero transaction costs.

In a nutshell, firms that do not profit from economies of scale in the management of the trading scheme will perceive higher marginal costs and, on the margin, emit less (abate more) than in a first-best cost minimum (see figure 1). In contrast, firms that do profit from economies of scale will perceive lower marginal control costs and consequently will emit more (abate less) than under a first-best situation with zero transaction costs.

An overall welfare loss results from the fact that under conditions described above, marginal abatement costs are not equated among all sources of emissions. The resulting welfare loss for firm i (see figure 1) can be determined given the marginal abatement cost curve $c'_e(e_i)$, first-best emissions level e_i^*, second-best emissions level under transaction costs $\tilde{e}_i$, and the price per unit emissions p which is assumed to be exogenous for convenience[13]

$$\Delta W_i = \int_0^{\tilde{e}_i} c'_e(e_i)de - \int_0^{e_i^*} c'_e(e_i)de + (e_i^* - \tilde{e}_i)p. \quad (15)$$

The overall welfare loss is derived by summing up individual welfare losses of regulated firms $i = 1 \dots n$

$$\Delta W = \sum_{i=1}^{n} \left[\int_0^{\tilde{e}_i} c'_e(e_i)de - \int_0^{e_i^*} c'_e(e_i)de + (e_i^* - \tilde{e}_i)p\right]. \quad (16)$$

[13] Since differing incentives for abatement might also have an impact on the permit price, the consequences of transaction costs on welfare might differ from (15) and (16), dependent on the distribution of firms under regulation and the occurring economies of scale in the management of the trading scheme. Since a broader discussion of the impact of transaction costs on the permit price is clearly out of the scope of this paper, the topic is left for future discussion.

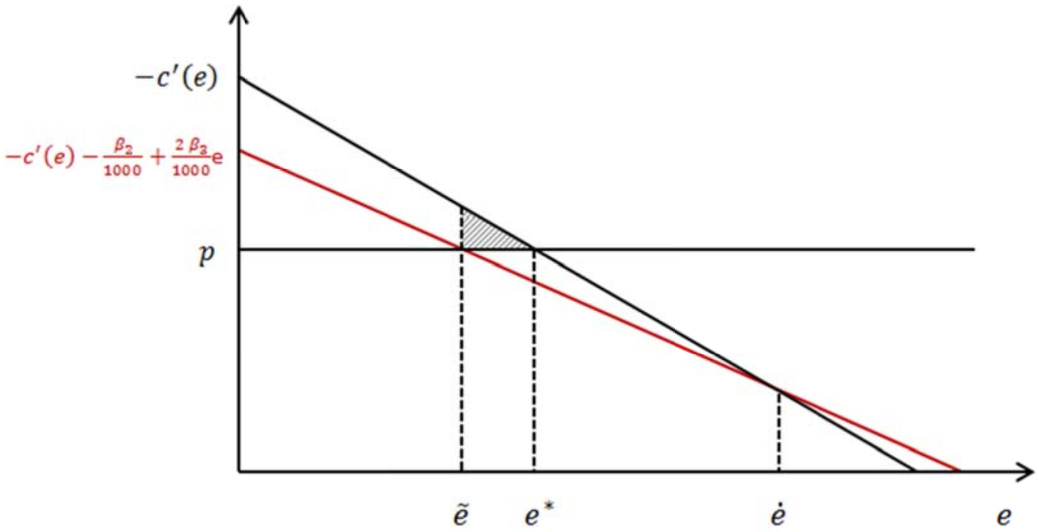

Figure 1: Shifted marginal costs and corresponding welfare loss (gray shaded). The figure illustrates the case of an emitter that is not able to realize economies of scale and faces higher overall costs per unit emissions compared to the first-best case without transaction costs. First-best emissions level would be e^*, the corresponding emissions level under transaction costs is $\tilde{e}$, economies of scale would be realized at any $e > \dot{e}$.

A second aspect of the analysis is related to the structuring of markets, or more general, it is related to the way institutional economics sees transaction costs. High average transaction costs could, on the margin, lead to a situation where smaller emitters exit the market. It is important to note that market exit would in such a situation not be driven by issues of competitiveness, but would be caused by 'disturbing effects' from environmental regulation. To state the case more clearly, average transaction costs, which are defined by overall transaction costs divided by annual emissions are plotted in figure 2 based on fitted values of the estimation presented in table 2.

As the figure shows, average transaction costs are relatively high for smaller emitters and drop sharply with rising annual emissions of a firm. At low emissions levels, such as 5,000 or 10,000 tCO_2 p.a., doubling emissions leads to a reduction of average transaction costs by almost 50 percent. For emissions levels larger than 25,000 tCO_2 per year, transaction costs converge to a relatively low level.

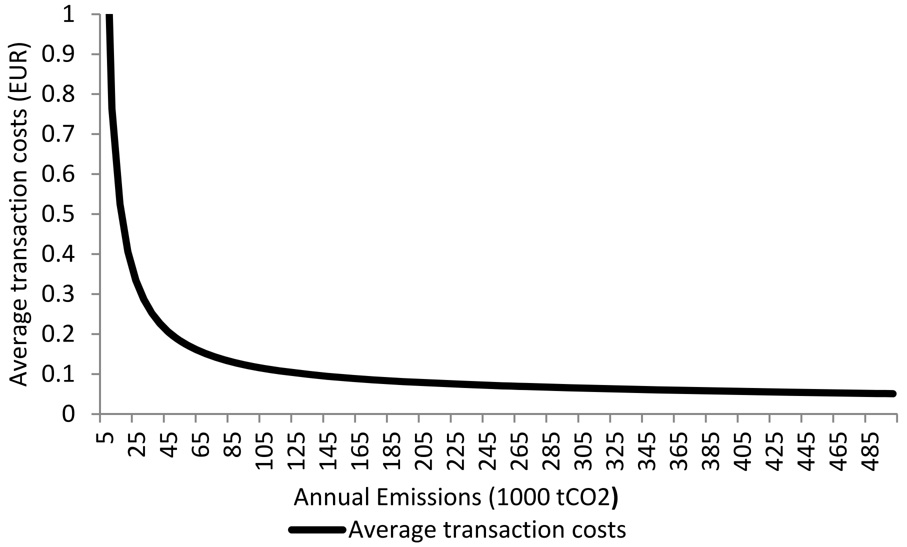

Figure 2: Average transaction costs (fitted values) of firms in the EU ETS in Germany

Public authorities in Germany are aware of the problem of high burdens for smaller emitters under the EU ETS. Consequently, several measures were taken to reduce transaction costs for smaller emitters (less than 25,000 tCO_2 emissions p.a.), which will come into force in 2013. These measures include an opt-out provision given that emitters reduce a certain amount of emissions voluntarily. Alternatively, small emitters could be allowed to report verified emissions on a two-year basis instead of the current annual reporting. Whether these measures will deliver the intended results is in the first place an empirical question. However, the underlying principle clearly is that uneven transaction costs shall be reduced by an uneven treatment of regulated sources. In the best case this would shift transaction costs from regulated emitters to public authorities, which can be expected to face higher expenditures in the case of a more differentiated treatment of regulated sources.

When all installations regulated by the EU ETS in Germany are aggregated to the firm level, 816 firms can be identified. After fitting the simple OLS model presented in table 2 to annual emissions levels of 2010, overall transaction costs of German firms under the EU ETS can be calculated. In sum, transaction costs from the EU ETS in Germany amount to EUR 8.7 million. This implies that German companies spent EUR 8.7 million for the management of emissions trading, including MRV activities, administrative costs of permit trades and information gathering.

Finally, what is left for discussion is the possible future development of transaction costs in the EU ETS. As the available data show, transaction costs for trading and informational costs are currently relatively low (31 percent of overall transaction costs) compared to transaction costs for MRV (69 percent of overall transaction costs). Since the data refer to the year 2009 and 2010, they reflect the current situation. Future changes in the EU ETS will likely influence transaction costs. While most firms currently receive sufficient free allocation, it is expected that from 2013 onward most firms will need to purchase additional permits for compliance due to strongly decreased free allocation. Free allocation shall be phased out completely until 2027. As a consequence, an increasing number of firms, including small emitters, will have to purchase permits on the market, which will likely lead to increasing costs for transacting over time. Informational costs have turned out to be of minor importance in the current state of the EU ETS. Given moderate permit prices in 2009 and 2010 (about EUR 15), the incentives for firms to abate were moderate and most abatement actions were carried out by measures that increased energy efficiency and reduced emissions as a side effect (Löschel et al., 2011, 2010). Given that the cap on emissions in Europe will decrease over time and permit prices are expected to increase, firms will likely face significant incentives to lower their emissions in the future. In that case, informational costs, e.g. from searching for adequate technology for abatement, might increase as well.

7. Conclusion

Based on survey data from German companies in the EU emissions trading scheme, it was shown that firms face significant transaction costs from GHG regulation. Overall annual transaction costs in the EU ETS in Germany are estimated to amount to EUR 8.7 million. By far the largest share of transaction costs (69 percent) stem from measurement, reporting and verification of emissions. Transaction costs for permit trading (19.57 percent of overall transaction costs) and informational costs (11.43 percent of transaction costs) occur to a moderate extent under the current design of the EU ETS. Based on OLS and non-parametric estimation, it was shown that transaction costs for MRV activities and permit trading are non-linear in annual emissions of a firm and annual trading volumes respectively.

The existence of non-linear transaction costs implies that firms face economies of scale in the management of emissions trading. In practice and based on available data from Germany, firms with annual emissions of more than 1 million tons of CO_2 realize such economies of scale. It has been shown that the existence of non-linear transaction costs leads to losses in economic efficiency compared to a first-best situation with zero transaction costs. Since transaction costs enter the marginal condition, firms that do not profit from economies of scale (less than 1 million tCO_2 p.a.) emit less (abate more) than in the first-best optimum. Accordingly, firms that are able to realize economies of scale emit more (abate less) compared to the first-best case. As a result, transaction costs prevent marginal abatement costs to be equated over all regulated emitters.

Another negative consequence of transaction costs in the EU ETS stems from extreme average transaction costs faced by small emitters. On the margin, high average transaction costs could lead to larger average firm size (in terms of annual emissions) over time. Given that currently more than 50 percent of firms under the EU ETS in Germany emit less than 25,000 tCO_2 per annum, a large number of firms face high average transaction costs compared to larger emitters. For instance, a firm that emits 1 million tons of CO_2 each year faces average transaction costs of roughly EUR 0.03 per ton of CO_2. In contrast, a firm that emits 10,000 tCO_2 each year faces average transaction costs of about EUR 0.76 per ton of CO_2. It is likely that in certain cases, e.g. if electricity or heat is needed by a firm, small emitters may choose to 'buy' rather than to 'make' and stop producing electricity or heat internally. Although this does not necessarily imply a negative effect on environmental efficiency of emissions trading or carbon leakage, it could lead to increasing concentration of power in the market of permits by increased average firm size and a decreased number of participants in the permit market. Such effects are likely to occur after several years or decades if they are present at all. Consequently, an empirical examination of the case has to be postponed to later years.

Finally it has to be said that the results also have implications for price regulation (tax). The reason is that currently, the largest share of transaction costs in the EU ETS stem from measurement, reporting and verification. If MRV requirements would be the same under price and quantity regulation, also price regulation would incur considerable transaction costs. Since trading volumes, the number of trades, and the overall need for information might increase with a decreasing 'cap' on emissions and lower free allocation in the EU ETS until 2020, transaction costs from permit trading and informational costs will have to be examined in more detail, either by ex-ante numerical simulations or ex-post by carrying out empirical studies as soon as adequate data is available.

Table 3: Results of OLS Estimation

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	log of overall transaction costs log(OTC)				**log of TC for MRV** log(TCMRV)			**log of TC for trading** log(TCT)			**log of TC for information** log(TCINFO)		
Verem	0.0006557	0.00285	0.002535	0.0026407	0.0006994	0.0025225	0.0026302				0.0014252	0.0083036	
	(2.63)***	(5.17)***	(4.61)***	(2.97)***	(3.05)***	(5.81)***	(4.33)***				(1.30)	(2.16)**	
Verem²		-1.43 e-06	-1.33 e-06	-1.30 e-06		-1.21 e-06	-1.26 e-06					-0.000017	
		(-5.03)***	(-4.51)***	(-2.79)***		(-5.34)***	(-4.28)***					(-2.09)**	
Tvolume								0.0061546	0.0113131	0.0068062			
								(2.72)***	(2.01)**	(2.86)***			
Tvolume²									-0.000015				
									(-0.78)				
D250			0.0429056	-0.0024796			0.0115922			-0.5195805			-0.5785433
			(0.32)	(-0.02)			(0.08)			(-1.52)			(-1.19)
D1000			0.4232761	0.4656723			0.2195526			0.2369411			-0.4456447
			(2.10)**	(2.18)**			(1.04)			(0.47)			(-0.80)
Instnr				-0.0031589			-0.009469						
				(-0.06)			(-0.18)						
Dcomb				0.1492277			0.2374577						
				(0.72)			(1.33)						
Dindus				0.0015297			0.1701644						0.7543177
				(0.01)			(1.06)						(1.77)*
Dtrade				0.2704519						-0.1067014			
				(1.79)*						(-0.32)			
Dtrademore				-0.5016913						-0.5731226			
				(-2.23)**						(-1.60)			
Dinfo				0.3304612						0.4597088			1.23718
				(1.89)						(1.40)			(2.48)**
Dmit				-0.0243595									-0.3285184
				(-0.16)									(-0.64)
Dassess				0.1764047									-0.198852
				(1.28)									(-0.53)
Dsell										-0.2906519			
										(-0.78)			
D2times				0.0236594			0.0117424			-0.6163033			-0.0542323
				(0.19)			(0.10)			(-2.15)**			(-0.12)
_cons	8.849373	8.682738	8.627783	8.290831	8.584661	8.443316	8.136628	6.913234	6.832152	7.620053	7.500863	7.21981	7.489783
	(118.36)***	(110.60)***	(77.06)***	(35.52)***	(127.05)***	(118.43)***	(38.98)***	(45.02)***	(40.16)***	(14.93)***	(29.09)***	(22.62)***	(14.45)***
R²	0.0750	0.1922	0.2199	0.3309	0.1056	0.2099	0.2398	0.2003	0.2107	0.3306	0.0191	0.0675	0.2352
F	6.92***	13.38***	8.45***	4.40***	9.31***	17.39***	5.29***	7.41***	7.49***	3.17***	1.68	2.33	2.58**
N	150	150	150	132	150	150	150	76	76	72	48	48	45
DF	148	147	145	118	148	147	141	74	73	63	46	45	37
AIC	373.4213	355.0963	353.856	314.2905	336.4578	319.8522	326.0751	250.0557	251.0607	239.7656	160.7096	160.2844	154.2136

*** P>|t|=0.01, ** P>|t|=0.05, * P>|t|=0.10, for all estimations robust standard errors where used, t-values in brackets

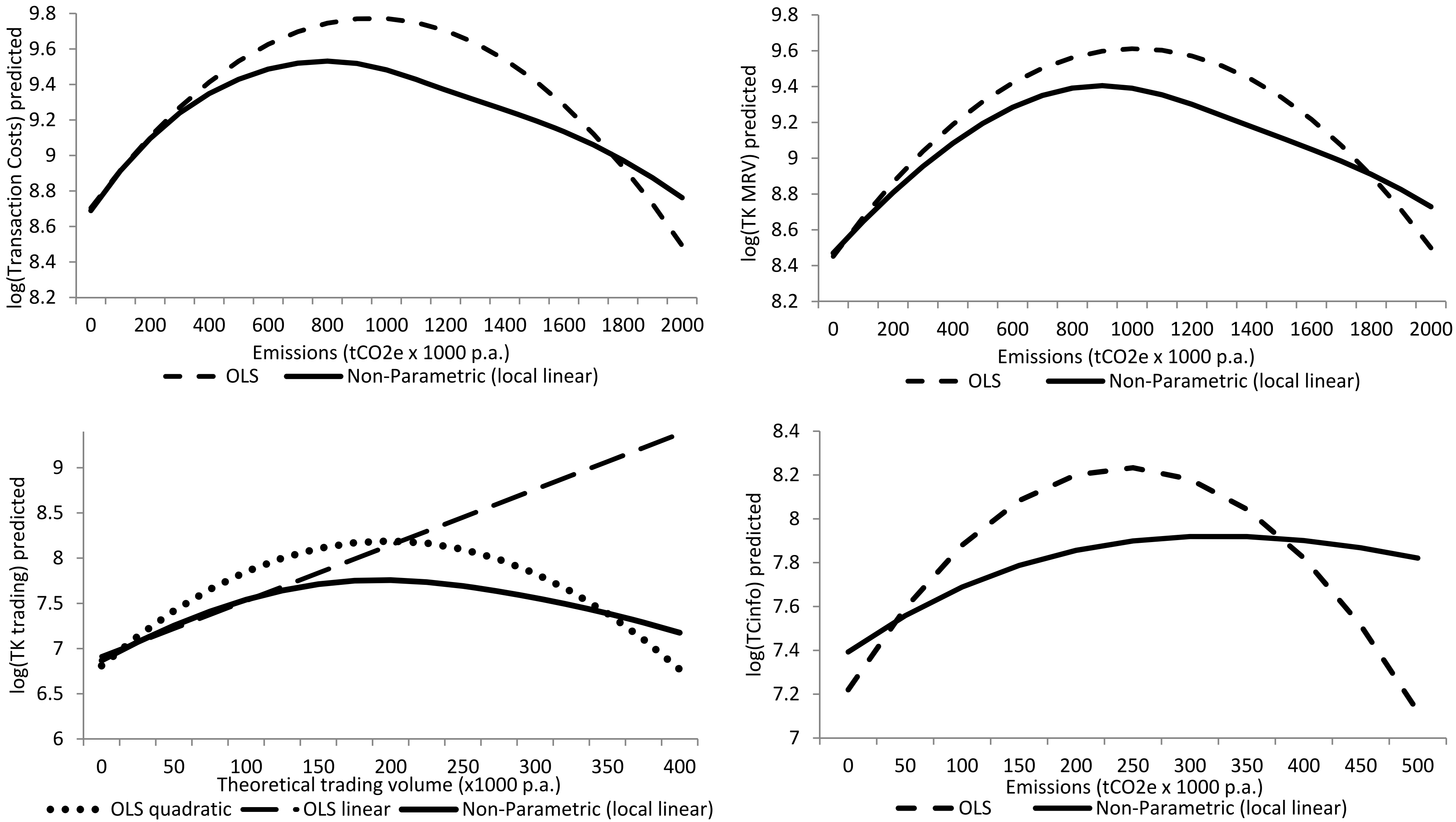

Figure 3: Comparison of fitted OLS and fitted non-parametric estimation. The upper left figure plots fitted values of overall transaction costs (OLS reference model is no. 2). The upper right figure plots fitted values of transaction costs for MRV (OLS reference model is no. 6). The lower left figure plots fitted values of transaction costs for trading (OLS reference models are no. 8 and no. 9). The lower right figure plots informational costs (OLS reference model is no. 12).

8. References

Allen, D. W. (2000). Transaction Costs. In B. Boudewijn & G. De Geest (Eds.), *Encyclopedia of Law and Economics, Volume I. The History and Methodology of Law and Economics*. Cheltenham: Edward Elgar.

Baumol, W. J. (1952). The Transactions Demand for Cash: An Inventory Theoretic Approach. *Quarterly Journal of Economics*, *66*(4), 545-556.

Baumol, W. J., & Oates, W. E. (1971). The use of standards and prices for protection of the environment. *The Swedish Journal of Economics*, *73*(1), 42–54.

Cason, T. N., & Gangadharan, L. (2003). Transactions Costs in Tradable Permit Markets: An Experimental Study of Pollution Market Designs. *Journal of Regulatory Economics*, *23*(2), 145-165.

Coase, R. H. (1937). The Nature of the Firm. *Economica*, *4*(16), 386-405.

Coase, R. H. (1960). The Problem of Social Cost. *Journal of Law and Economics*, *3*(October 1960), 1-44.

Crals, E., & Vereeck, L. (2005). Taxes, Tradable Rights and Transaction Costs. *European Journal of Law and Economics*, *20*(2), 199-223.

Dahlman, C. J. (1979). The Problem of Externality. *Journal of Law and Economics*, *22*(1), 141-162. The University of Chicago Law School.

Downing, P. B., & White, J. L. (1986). Innovation in pollution control. *Journal of Environmental Economics and Management*, *13*(1), 18-29.

Foley, D. K. (1970). Economic Equilibrium with Costly Marketing. *Journal of Economic Theory*, *2*(3), 276-291.

Hahn, R. W., & Hester, G. L. (1989). Where Did All the Markets Go - An Analysis of EPA's Emissions Trading Program. *Yale Journal on Regulation*, *6*, 109-153.

Hanemann, M. (2009). The Role of Emission Trading in Domestic Climate Policy. *Energy Journal*, *30*(Special Issue 2), 79-114.

Hicks, J. R. (1935). A Suggestion for Simplifying the Theory of Money. *Economica (New Series)*, *2*(5), 1-19.

Jaraitė, J., Convery, F., & Di Maria, C. (2010). Transaction costs for firms in the EU ETS: lessons from Ireland. *Climate Policy*, *10*(2), 190-215.

Klaes, M. (2000). The History of the Concept of Transaction Costs: Neglected Aspects. *Journal of the History of Economic Thought*, *22*(02), 191-216.

Li, Q., & Racine, J. S. (2007). *Nonparametric Econometrics - Theory and Practice*. Princeton University Press.

Löschel, A., Brockmann, K. L., Heindl, P., Lutz, B., & Schumacher, J. (2011). *KfW/ZEW CO2 Barometer 2011: Hoher Anpassungsbedarf im EU-Emissionshandel ab 2013 – deutliche Defizite bei der Vorbereitung in den Unternehmen*. Frankfurt am Main. Retrieved from http://ftp.zew.de/pub/zew-docs/co2panel/CO2Barometer2011.pdf

Löschel, A., Kiehl, K., Heindl, P., Lo, V., Koschel, H., & Koesler, S. (2010). *KfW/ZEW CO2 Barometer 2010: Effizienzpotenziale des Emissionshandels noch nicht ausgeschöpft – Strategien und management deutscher Unternehmen*. Frankfurt am Main. Retrieved from ftp://ftp.zew.de/pub/zew-docs/co2panel/CO2Barometer2010.pdf

Marschak, J. (1950). The Rationale of the Demand for Money and of "Money Illusion." *Metroeconomica*, *2*(2), 71-100.

Milliman, S. R., & Prince, R. (1989). Firm incentives to promote technological change in pollution control. *Journal of Environmental Economics and Management*, *17*(3), 247-265.

Montero, J.-P. (1998). Marketable pollution permits with uncertainty and transaction costs. *Resource and Energy Economics*, *20*(1), 27-50.

Montgomery, W. D. (1972). Markets in Licenses and Efficient Pollution Control Programs. *Journal of Economic Theory*, *5*, 395-418.

Solomon, B. D. (1999). New directions in emissions trading: the potential contribution of new institutional economics. *Ecological Economics*, *30*(3), 371-387.

Stavins, R. N. (1995). Transaction Costs and Tradeable Permits. *Journal of Environmental Economics and Management*, *29*(2), 133-148.

Tietenberg, T. H. (2006). *Emissions Trading: Principles and Practice* (2nd ed.). Washington D.C.: RFF Press.

Tobin, J. (1956). The Interest-Elasticity of Transactions Demand for Cash. *Review of Economics and Statistics*, *38*(3), 241-247.

Williamson, O. E. (1971). The Vertical Integration of Production: Market Failure Considerations. *American Economic Review*, *61*(2), 112-123.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data*. MIT Press.