Title: Did the EU ETS make a difference? An empirical assessment using Lithuanian firm-level data

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Abstract. We use a panel dataset of about 5,000 Lithuanian firms between 2003 and 2010, to assess the impact of the EU ETS on the environmental and economic performance of participating firms. Using a matching methodology, we are able to estimate the causal impact of EU ETS participation on CO_2 emissions, CO_2 intensity, investment behaviour and profitability of participating firms. Our results show that ETS participation did not lead to a reduction in CO_2 emissions, while we identify a slight improvement in CO_2 intensity. ETS participants are shown to have retired part of their less efficient capital stock, and to have made modest additional investments from 2010. We also show that the EU ETS did not represent a drag on the profitability of participating firms.

1. Introduction

As the post-Doha political debate moves on from the old Kyoto framework towards a new post-2020 global policy regime, flexibility mechanisms, that theoretically facilitate the achievement of policy goals at least cost, take centre stage. In this context, emissions trading systems, with the possibility they offer to link emissions reduction efforts across space and time, seem poised to become one of the pillars upon which future cost-effective mitigation efforts will be built. As a consequence, there is considerable interest in understanding how these market-based instruments perform in practice. In particular, there is a growing appetite on the part of policy makers for empirical analyses that shed light on how participation in emissions trading systems affects the economic and environmental performance of regulated entities. To date, however, only a handful of studies have attempted such an analysis.

In this paper we exploit a previously unexplored firm-level dataset to investigate these

questions in the context of the European Union Emissions Trading System (EU ETS). A rich dataset of Lithuanian firms spanning the years between 2003 and 2010 allows us to investigate the impact of the EU ETS on emissions, profitability and investment decisions.

The unique features of the data allow us to directly compare emissions between ETS and non-ETS firms, something that, to the best of our knowledge, has not been possible before. While this is the main motivation for our choice of Lithuania as a case study, we believe that our findings can be informative about the behaviour of firms elsewhere in the EU ETS. Indeed, Lithuania's ETS coverage is sufficiently broad to suggest that the average treatment effects we estimate as a result of our empirical analysis - for example, as refers to emissions and emissions intensity – are broadly transferrable to firms operating elsewhere in the EU. Lithuania has a well-developed financial sector, its currency is pegged to the euro, and it is also an extremely open economy[1]; its larger firms, such as the ones in our dataset, operate across several markets, including ones outside of the EU.[2] Hence, information about the competitiveness challenges faced by Lithuanian firms is likely to be highly indicative of the challenges facing similar firms elsewhere. Finally, Lithuania has been one of the fastest growing economies in the EU for over a decade and, in this sense, the results from our analysis are also likely to be relevant to policy makers in other fast growing economies contemplating the introduction of emissions trading schemes.

Our analysis adds to the scant *ex-post* empirical literature on the EU ETS by investigating the

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[1] The ratio of international trade to GDP has exceeded 80 per cent since 2000, and 100 per cent since 2005. The latest figure available is 137 per cent, according to Statistics Lithuania (http://www.stat.gov.lt/).

[2] Russia is the largest Lithuania's trade partner representing 33 per cent of all imports and 17 per cent of all exports.

causal effects of the EU ETS on firm-level environmental and economic performance.[3] Exploiting the peculiar features of our data, we are able to make the most of the design characteristics of the EU ETS[4], and to construct a reliable counterfactual, i.e. believable estimate of the outcome variables that would have been observed in the absence of the EU ETS. Given that only a subset of firms in each sector were required to participate in the EU ETS, we can directly compare environmental and economic outcomes of ETS firms to those of similar firms outside the scheme. One important advantage of this approach is that the counterfactual estimates are free of the potentially confounding effects of changing economic conditions at country level, industry-wide production trends, and technological change.

The contribution of this paper is threefold. Firstly, we are the first – to the best of our knowledge – to be able to compare the evolution over time of CO_2 emissions by ETS firms to that of firms outside of the EU ETS. We do this within a classic non-experimental program evaluation framework, using matching algorithms to derive causal inferences on the impact of the program. Secondly, by exploiting a richer dataset than previously done in the literature, we are able to investigate the effect of the EU ETS on the economic performance of firms in greater detail. For example, we complement the analysis of firms' profitability with a discussion of investment decisions. Finally, our dataset spans the first and (most of)

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[3] There is a large body of literature attempting *ex-ante* "evaluation" exercises on the EU ETS. Böhringer, Hoffmann, Lange, Löschel, and Moslener (2005) and Kemfert, Kohlhaas, Truong, and Protsenko (2006), for example, present evidence at the aggregate level, whereas Neuhoff, Keats, and Sato (2006) and Demailly and Quirion (2008), among others, discuss sectorial impacts.

[4] Ellerman, Convery, and de Perthuis (2010) is probably the most authoritative reference on the EU ETS. It contains a detailed discussion of the design of the ETS and provides a comprehensive analysis of Phase I.

the second phase of the EU ETS (2004-2010), thus extending and updating previous results.

Our analysis starts by assessing the environmental consequences of the EU ETS. We first look into actual emissions reductions – so called "abatement" – by comparing actual CO_2 emissions with counterfactual CO_2 emissions. Only a handful of previous studies have documented aggregate emissions abatement in the first phase of the EU ETS. Ellerman and Buchner (2008) calculate that 130-200 Mt of CO_2 were abated in 2005 and 140-220 Mt in 2006, across all EU member states. Anderson and Di Maria (2011) improve on these results using more refined data for 2005-2007 and estimate overall abatement at 247 Mt of CO_2 during the first phase. They also find evidence of emissions "inflation", however, i.e. they show that several countries had actual emissions in excess of the counterfactual. Delarue, Ellerman, and D'Haeseleer (2010), Pettersson, Söderholm, and Lundmark (2012), Linden, Mäkelä, and Uusivuori (2013), and Widerberg and Wråke (2009) explicitly focus on abatement in power generation. Delarue, Ellerman, and D'Haeseleer (2010) analyse the power sector's CO_2 short-term abatement possibilities through fuel switching. The authors estimate abatement of the European power sector's to be in the range of 34.4-63.6 Mt of CO_2 in 2005, and 19.2-35 Mt in 2006. Pettersson, Söderholm, and Lundmark (2012) use a Generalized-Leontieff model of the electricity sector calibrated on data from eight western European countries – Austria, Belgium, Germany, Ireland, Italy, Netherlands, Spain and the UK – over the time period 1980-2004 to support the view that the elasticity of substitution, especially between oil and gas, may be rather high in the short run. Their model suggests that an allowance price of US$90 would lead to a 2 per cent decrease in CO_2 emissions, via fuel-switching only (using 2004 as the base year, this is equivalent to 18Mt of CO_2). Linden, Mäkelä, and Uusivuori (2013) find that the EU ETS has short term impacts on the fuel mixes

of the energy plants in Finland. The elasticity of substitution between fossil and non-fossil fuels is larger under the ETS. Widerberg and Wråke (2009) look at the effect of the carbon price on the CO_2 emissions intensity of the Swedish electricity sector for the period 2004–2008. They find no statistically significant link between the price of CO_2 and CO_2 emissions, and conclude that it is unlikely that there are significant volumes of low-cost CO_2 abatement possibilities with short response times in the Swedish electricity sector. Finally, Abrell, Faye, and Zachmann (2011), use CITL data to test whether the EU ETS induced acceleration in emissions reductions, and find some evidence to the positive. In the current paper, for the first time we are able to look at abatement at the firm level, thanks to the unique characteristics of our dataset.

We then investigate the economic consequences of carbon pricing. Emission reductions generally entail costs as resources need to be reallocated from production activities to emissions reduction. In principle, these costs depend on the stringency of the carbon constraint, the tighter the cap the higher the marginal abatement cost or CO_2 price, and the greater the cost, all else being equal. Since the EU is the only region in the world in which a carbon price is applied on such a scale, the EU ETS might have serious implications in terms of the loss of competiveness it causes to ETS firms versus both European firms outside of the EU ETS, and their non-European competitors. We address the impact of the EU ETS on competitiveness by looking at a firm's ability to generate profits. In doing this, we can also gauge the implications of the free permits allocation for firms' profitability. Our dataset also allows us to investigate whether ETS firms exhibit a different behaviour relative to their non-ETS counterparts when it comes to investment in tangible capital. This is particularly important in terms of the future competitive position and profitability of regulated firms.

To date, only a few studies have analysed the impact of the EU ETS on firm competitiveness, profitability or general economic performance *ex-post*.[5] Potentially negative impacts on competitiveness have understandably been the main concern of firms within the EU ETS, and have been the focus of most empirical analyses. Energy-intensive and trade-exposed industrial activities namely cement, glass, iron and steel, paper and pulp, refining and aluminium, are arguably the most exposed among the EU ETS sectors in terms of international competition. Empirical research using trade data (imports into the EU as well as exports from the European Union), however, has found no evidence in support of the hypothesis that the introduction of the EU ETS placed such sectors at a competitive disadvantage, at least in the first trading period (Ellerman, Convery, and de Perthuis 2010). Similar conclusions are reached by Anger and Oberndorfer (2008) who do not find that the first two years of the EU ETS had a negative effect on the revenue of German over-allocated and under-allocated ETS firms. Yu (2011) uses firm-level data to analyse the effects of ETS participation on the profitability of Swedish power generating firms in 2005 and 2006. Her results do not show any significant impact of the EU ETS on profitability in 2005, but suggest a significant negative impact in 2006, which, she argues, might be due to the collapse of the price of European Union Allowances (EUA). Abrell, Faye, and Zachmann (2011) assess the impact of the EU ETS on firm competitiveness based on data on 2,101 European ETS firms (3,608 installations) during 2005-2008 and find a modest impact on ETS firms' economic performance. Chan, Shanjun, and Zhang (2012) use a panel of 5,873 firms in 10 European countries during 2001-2009 and seek to assess the impact of the EU ETS on three variables through which the effects on firm competitiveness may manifest – unit material costs,

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[5] See Zhang and Wei (2010) and Venmans (2012) for overviews of research on the EU ETS.

employment and revenue. Their findings do not substantiate concerns over carbon leakage, job losses or industry competitiveness. Overall, all these studies suggest that the concerns about the negative impact of EU ETS on competitiveness can be dismissed, at least in the first trading years.

The rest of this paper proceeds as follows. Section 2 provides some background on Lithuania's experience with the EU ETS; Section 3 outlines the research design and the data sources used in this analysis; Section 4 presents and discusses the empirical results; finally, Section 5 summarises and concludes.

2. Lithuania in the EU ETS

Lithuania's overall CO_2 emissions increased between 2000 and 2007 – peaking at 15.81 Mt – and subsequently decreased to just below 14Mt in 2010 (See Table 1). In per-capita terms, emissions increased from 3.37 tonnes in 2000 to 4.12 tonnes in 2010. On average, the ETS sectors contributed around 43 per cent of total CO_2 emissions between 2005 and 2010.

Table 1 Lithuania's total, per capita and ETS CO_2 emissions

Year	Total CO_2 emissions, Mt	CO_2 emissions per capita, t	ETS CO_2 Emissions, Mt
2000	12.06	3.37	
2001	12.75	3.60	
2002	12.88	3.65	
2003	12.60	3.66	
2004	13.42	3.84	
2005	14.19	4.09	6.60
2006	14.57	4.23	6.52
2007	15.81	4.66	6.00
2008	15.09	4.49	6.10
2009	12.95	3.86	5.79
2010	13.84	4.12	6.39

Source: European Environmental Agency (EEA).

Under the Kyoto agreement, Lithuania had a target to reduce its CO_2 emissions by 8 per cent relative to the 1990 level by 2008-2012. In reality, the fact that Lithuania gained independence from the Soviet Union in 1990 and subsequently underwent major structural changes during its transition to a market economy explains why emissions in Lithuania have been significantly below the Kyoto target since 1993.[6] Therefore, Lithuania recognised that it would have no difficulty implementing the Kyoto target and its first period ETS allocation would reflect forecasted business-as-usual emissions. Lithuania accessed the European Union in May 2004, and it was fully integrated into the first phase of the EU ETS. Its first period National Allocation Plan (NAP) was finalised on 27 December 2004 (Zapfel 2007).

Table 2 summarises the first period permit allocation for Lithuania. In the first period, the NAP allocated over 36 million EUAs to 93 installations. As a consequence, Lithuanian installations had a net long position of 15.40 million EUAs (almost 45 per cent when compared with the initial allocation excluding unexecuted allowances).[7]

The significant over-allocation of permits to Lithuanian's firms came about as the result of wrong expectations in terms of the impact of changes in the Lithuanian electric power market following the closure of the first reactor unit of the Ignalina Nuclear Power Plant (Ignalina NPP) on 31 December 2004. Indeed, at the time the NAP was being drafted, there was a widespread belief that this would imply a large increase in fossil-fuel-based

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[6] According to GHG inventory data under the United Nations Framework Convention on Climate Change, in 2007 GHG emissions in Lithuania were down 53 per cent on the 1990 level. During this period, real GDP increased by 101 per cent.

[7] The CITL does not incorporate the data on allocated reserves. See McGuinness and Trotignon (2007) for a detailed discussions on how information on the reserves can be combined with the CITL data.

generation. This was the main reason behind the increase in the number of EUAs allocated to Lithuanian energy enterprises. The extent of this increase is illustrated by Štreimikiene (2008): in 1998, CO_2 emissions from power-generating firms participating in the EU ETS accounted for 5.19 Mt, while the annual first period allocation of those firms was 7.59 Mt of CO_2. In fact, during the first trading period, the actual verified emissions for combustion installations, which are mainly owned by power generating firms, were on average about 3.63 Mt of CO_2 per annum.

Table 2 Lithuania's first period allocation, 2005-2007

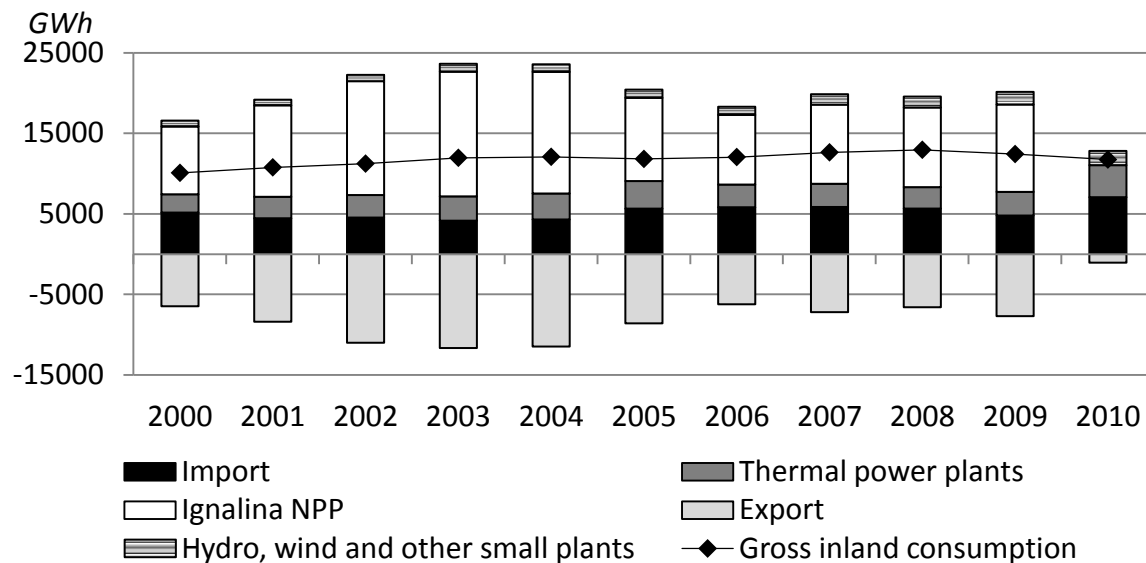| Recipient	EUAs
For issuance to not new entrants	34 394 402
Not yet executed	10 142
In reserve	2 391 640
Total	36 796 184
Verified emissions	18 995 650
Net position (without reserves)	15 398 752
Net position, % (without reserves)	44.77

Note: not yet executed EUAs are not taken into account.
Sources: CITL as of 1 August 2010 and the authors' calculations.

The two main reasons underlying this shortfall in emissions were that the second unit at Ignalina NPP operated very efficiently throughout 2005, and the time spent for regular maintenance was kept to a minimum, and the concomitant increase in natural gas prices in 2005. Given the increased cost of domestic gas-fired generation, the growing electricity demand was met by electricity imported from Russia and Estonia, rather than by increases in domestic supply (Štreimikiene 2008). Electricity produced by Ignalina NPP decreased from 15,102 GWh in 2004 to 9,914 GWh on average during the period 2005-2009, but electricity import increased from 4,293 GWh in 2004 to 5,546 GWh on average in the same period. It is also worth mentioning that Lithuania remained a net exporter of electricity through 2009

(See Figure 1).

Figure 1 Lithuania's electricity balance, 2000-2010

Source: Lithuanian Energy Institute

As a consequence of the generous allocation of permits, Lithuanian firms were able to sell large amounts of allowances and benefit from wind-fall profits. Table 3 reproduces information from Ellerman and Trotingnon (2009) and summarises information on the flows of EUAs from Lithuania. Not surprisingly, Lithuania was a net exporter of allowances in the first trading period, exporting almost 11 million EUAs. Three quarters of the Lithuanian EUAs were transferred in 2007 when the price of carbon was at its lowest. Assuming that surrendered allowances were acquired at the average price for the intervals before and between the end of April, dates when allowances were to be surrendered, at the time when these flows were monetised, we conclude that Lithuanian installations accrued most of their revenue from selling EUAs in 2006 when the price of EUAs averaged at 9.57 EUR.[8]

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[8] It is important to note that Lithuania's Greenhouse Gas Emissions Allowance Registry started functioning only in November 2005. Only since then were ETS firms able to trade their EUAs (National Audit Office of Lithuania 2008). This might explain why most of the EUAs were sold in 2006 and 2007 rather than in 2005.

Table 3 Lithuania's net allowance export and import flows, 2005-2007

	2005-07	2005	2006	2007
EUAs sold, millions	10.93	0.42	2.36	8.15
Revenue , millions €	32.20	8.50	22.60	1.10

Source: Adapted from Ellerman and Trotingnon (2009).

We can confirm that Lithuanian installations monetised their surpluses at very high prices thanks to the information collected by the National Audit Office of Lithuania on Lithuanian firms partly controlled by the Lithuanian Government. For these firms, we also have information about the way they used the revenue from allowances' sales in the first trading period. Table 4 shows that the average price received per EUA ranges from 28.1 EUR to 5.79 EUR. The Lithuanian power plant, which was expected to cover the energy shortage due to a closure of unit 1 at Ignalina NPP, sold the 4.65 Mt of EUAs out of received 7.40 Mt in total. It is also important to note that only about a tenth of this revenue was used for emission abatement.

Table 4 Use of revenues by Lithuania's ETS firms from sold allowances, 2005-2007

Firms	Sold allowances		EUA price[1], EUR	Use of revenues form sold EUAs[2]		
	'000 EUAs	Revenue[2]		GHG investment[3]	Other	Unused
Lithuanian PP	4650	26750.8	5.8	189.1	2891.0	23670.6
Siauliai energy	30	766.0	25.5	117.6	602.7	45.8
Klaipeda energy	40	1124.0	28.1	1124.0	-	-
Panevezys energy	85	2200.2	25.8	1131.5	1068.7	-
Mazeikiu district heat	90	778.8	8.7	778.8	-	-
Taurages district heat	42	861.3	20.6	861.3	-	-
Utenos district heat	44	1141.1	26.1	10.7	261.5	-
JSC Geoterma	33	533.5	16.2	10.7	522.8	868.9
Total	5014	34155.8	7.0	4223.8	5346.7	24585.3

Notes: 1. EUA price is average. 2. Revenue is in thousands €. 3. GHG investments include transaction costs.
Sources: National Audit Office of Lithuania (2008) and the authors' calculations.

The operation of ETS firms during the first period provided useful information that was used

as a basis for the second period NAP (2008-2012). Consequently, the annual second period allocation for Lithuanian installations was significantly reduced, even allowing for the envisioned closure of the Ignalina NPP from January 2010 onwards. The NAPs for the second trading period were approved before the start of 2008.

Despite the tighter second period allocation, the compliance results for the second trading period (2008-2012) reveal that in total ETS firms in Lithuania were still significantly over-allocated (see Table 5). During 2008-2012 ETS firms in Lithuania received 39.64 million of EUAs. Lithuanian installations had the net long position of 10.03 million of EUAs (25.31 per cent when compared with the initial allocation). Again, this suggests that the second period allocation did not create strong incentives for ETS firms to mitigate their CO_2 emissions, especially in light of the low level of EUAs prices over most of this period and of the increasing realisation of over-supply of permits after the financial crisis of 2008-2009.

Table 5 Lithuania's compliance during the second trading period, 2008-2011

	Allocated EUAs	Verified CO_2 emissions, t	Net position	Net position, %
2008	7 509 636	6 103 720	1 405 916	18.72
2009	7 568 316	5 786 742	1 781 574	23.54
2010	8 155 470	6 393 952	1 761 518	21.60
2011	8 037 268	5 606 425	2 430 843	30.24
2012	8 371 774	5 718 037	2 653 737	31.70
TOTAL	39 642 464	29 608 876	10 033 588	25.31

Source: European Environmental Agency as of 1 July 2013 and the authors' calculations.

3. Empirical Methodology and Data

3.1. Empirical framework

The main goal of this paper is to empirically estimate the changes in a number of firms' environmental and economic performance indicators relative to what would have occurred

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if the EU ETS had not been implemented. Since we want to identify the causal effect of the EU ETS, we exploit the unique design features of the EU ETS to construct tenable and transparent estimates of counterfactual emissions and other outcome variables. As a counterfactual we use econometrically adjusted observed environmental and economic outcome variables at firms that were not subject to the EU ETS over the same period.

A firm in the EU can find itself in one out of two regulatory states: it may be regulated under the EU ETS, or it may find itself outside of the ETS remit and hence be allowed unconstrained CO_2 emissions. Let D be the indicator variable that identifies a firm's participation in the EU ETS. Hence, D_i is equal to 1, if the ith firm is in the EU ETS (that is the firm is "treated"). A firm, i, that is instead outside of the treated group is assumed to be unaffected by the EU ETS, and is identified by $D_i = 0$. All firms with $D_i = 0$ are said to belong to the control group. $Y_{it}(1)$ and $Y_{it}(0)$ denote potential outcomes at firm i and time t, conditional on participation and non-participation, respectively.

We are interested in estimating the average treatment effect on the treated:

$$\alpha_{TT} = E[Y_{it}(1) - Y_{it}(0)|D_i = 1], \qquad (1)$$

where t represents any year following the introduction of the EU ETS and α_{TT} measures the average treatment effect of the EU ETS on the desired outcome variable (e.g. the annual firm level CO_2 emissions).

CO_2 emissions and other outcome variables of ETS and non-ETS firms are observed prior to the implementation of the EU ETS and over several years following its introduction. Firm-level emissions data collected from ETS firms during the years following the introduction of the program can be used to identify $E[Y_{it}(1)|D_i = 1]$. The fundamental problem with causal

inference, however, is that we do not observe $E[Y_{it}(0)|D_i = 1]$, i.e. we do not know what would have happened to ETS firms if they had not participated in the scheme. To overcome this limitation, we take advantage of a key feature of the EU ETS, i.e. the fact that the EU ETS regulates only a subset of the largest CO_2 emitters located within the 27 EU member states. Moreover, the remaining firms are not subject to any other type of carbon constraint, at least in Lithuania. The incomplete programme participation provides us with a potential comparison group as we are able to use econometrically adjusted observations on outcome variables relative to non-participants, to estimate the unobserved counterfactuals.

The simplest estimate of α_{TT} is obtained using standard differences-in-differences (DiD) estimators. These estimators, however, may be biased if the variables related to firm-level outcomes vary significantly across the treatment and comparison groups. To reduce this potential bias we utilise the observable differences across ETS participants and non-participants to estimate α_{TT} by using semi-parametric matching estimators.[9]

Matching estimators, which are used extensively in non-experimental program evaluation,

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[9] As the EU ETS already includes the biggest emitters, it is unlikely to be able to find good non-ETS counterparts in terms of absolute emissions. The criteria according to which firms are included in the EU ETS along with a variety of matching algorithms (see below), however, allows us to find close non-ETS matches. The inclusion criteria are based on energy capacity and production at the installation level. In some cases an installation corresponds to a whole firm, but in many other cases it represents only a part of it. This suggests that there are firms which do not qualify for inclusion in the EU ETS based on the individual installation, but would qualify if the selection criteria were applied to the firm as a whole. Hence, it is the case that some of the non-ETS firms are closely comparable with ETS firms in terms of emissions at the *firm* level. In what follows, we discuss how we impose the common support property (e.g., Imbens, 2004), thus assuring that we have appropriate controls for even the largest ETS installations.

are an extension of standard regression approaches. Our general estimation strategy follows Heckman, Ichimura, and Todd (1997) and Heckman et al. (1998) who introduced the following DID matching estimator:

$$\propto_{MDID} = \frac{1}{N_1} \sum_{j \in I_1} \left\{ \left(Y_{j1}(1) - Y_{j0}(0) \right) - \sum_{k \in I_0} w_{jk}(Y_{k1}(0) - Y_{k0}(0)) \right\}, \tag{2}$$

where I_1 denotes the set of program participants; I_0 denotes the set of non-participants; and N_1 is the number of firms in the treatment group. The participants are indexed by j; the non-participants are indicated by k. The weight placed on individual k when constructing the counterfactual estimate for treated facility j is w_{jk}. Different matching estimators adopt different approaches to defining the weights w_{jk} used to scale the contribution of each participant. In general, when the observable characteristics, X_i, of an untreated unit k are closer to the characteristics of a treated facility j (relative to other facilities in the control group), the untreated unit k is weighted relatively more heavily in the construction of a counterfactual estimate for unit j.

Since the seminal work of Rosenbaum and Rubin (1983), propensity scores (i.e., the conditional probability of treatment) are used, rather than conditioning on all the relevant covariates. An important finding in the literature is that, if unconfoundedness holds, conditioning only on the propensity score assures the independence of D_i and $Y_i(0)$ (Imbens, 2004).[10] While a variety of the propensity-score-based matching algorithms are

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[10] Unconfoundedness, a term introduced by Rubin (1990), indicates the situation in which adjusting for differences in a fixed set of covariates removes biases in comparisons between treated and control entities, thus allowing for a causal interpretation of those adjusted differences.

available,[11] in what follows, we use the nearest neighbour (NN) and Kernel matching estimators. The NN estimator is the most straightforward matching estimator. An appropriate facility from the control group is selected as the matching partner for a treated facility on the basis of its exhibiting the closest propensity score. In our case, we use NN matching with replacement since each untreated firm can be used more than once as a match. Matching with replacement involves a trade-off between bias and variance. By allowing replacement, the average quality of matching will increase and the bias will decrease, especially when one has a relatively small group of comparable facilities in the control group, as we do.

The main difference between Kernel matching and NN matching is that instead of using only a few observations from the comparison group, weighted averages of all individuals are used in the control group to construct the counterfactual outcome. That is, it constructs a match for each treated entity using a kernel-weighted average over multiple entities in the control group. Smith and Todd (2005) note that Kernel matching can be seen as a weighted regression of the counterfactual outcome on an intercept with weights given by the kernel weights. The weights depend on the distance between each control group observation and the treated observation for which the counterfactual is being estimated. Thus, one major advantage of this approach is the lower variance which is achieved because more information is used. The main demerit of this approach is that it utilises all observations, including ones that are objectively poor matches. This problem is eased by properly imposing the common support condition.

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[11] See Caliendo and Kopeinig (2008) for a non-technical discussion about the properties of various matching estimators.

3.2. Data

Our primary data come from the annual "Sample survey of non-financial enterprises (F-01)" administered by Statistics Lithuania (LS). The survey collects data on the main financial indicators for the sampled enterprises. We use eight waves of the survey (2003-2010), whose sample sizes vary between 8,000 and 17,000 firms.

Sampled firms belong to NACE (Statistical classification of economic activities in the European Community) Revision sectors 10-40. We exclude firms belonging to NACE 4012 (Transmission of electricity), 4013 (Distribution and trade of electricity) and 4022 (Distribution and trade of gaseous fuels through mains) as these firms are service providers such as gas and electricity distributors.

The dataset includes fuel purchases, turnover, capital stock, and profits. Importantly, the dataset also includes a breakdown of fossil fuels expenditures by fuel type. This unique feature allows us to infer quantities purchased from the expenditure data. Applying average emissions coefficients to the estimated quantities, we are able to obtain estimates of CO_2 emissions by both ETS and non-ETS firms (see the Appendix). This allows us to compare changes in CO_2 emissions by ETS firms with the behaviour of unregulated firms outside the ETS. [12] Unfortunately, the disaggregated fossil fuels expenditure series have been

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[12] We were able to identify ETS firms thanks to the collaboration of the LS, who matched sampled firms to a list of Lithuanian firms participating in the EU ETS prepared by the authors, based on the CITL installation data. For confidentiality reasons, however, we were not able to obtain a matched dataset of Lithuanian firms with CITL data.

discontinued from 2008; hence we are only able to conduct our analysis of CO_2 emissions until the end of phase 1, in 2007.

Due to the sampling methodology, the data set is strongly unbalanced. To avoid biasing our estimations, we restrict our analysis using the largest possible balanced panel. As a consequence of this adjustment, some firms drop from our sample.

A complete list of the variables used in the analysis, together with the usual set of descriptive statistics is presented in Table 6. The data are summarised for the balanced sample running from 2003 until 2010, broken down by EU ETS participation status.

The data exhibit notable differences between ETS and non-ETS firms. As expected, ETS firms on average emit more CO_2, produce more output, and are more capital intensive. On the other hand, ETS firms on average are less profitable than non-ETS ones.

Table 6 Descriptive statistics, Lithuania 2003-2007/2010

Variable	Period	Measurement Unit	ETS firms			Non-ETS firms		
			Obs.	Mean	Std. dev.	Obs.	Mean	Std. dev.
Fossil fuel expenditure	2003-2007	'000 LTL	205	21 898	64 760	2 800	370	1 331
Fossil fuel CO_2 emissions	2003-2007	Kilo tonnes	205	139.2	377.2	2 800	1.645	5.897
Fossil fuel CO_2 emissions/turnover	2003-2007	Tonnes/'000 LTL	205	1.309	1.394	2 800	0.110	0.345
Turnover	2003-2010	'000 LTL	328	120 061	217 734	4 480	26 371	67 292
Tangible capital assets	2003-2010	'000 LTL	328	110 212	272 518	4 480	12 274	84 873
Net gross profit before tax/turnover	2003-2010	'000 LTL/'000 LTL	328	-0.052	0.450	4 480	0.040	0.220

Notes:

1. All monetary variables are in real terms.
2. €1 = LTL 3.4528

Sources: Statistics Lithuania and the authors' calculations.

4. Results

4.1 Matching

To estimate a propensity score, i.e. the probability that a firm is regulated under the EU ETS based on their observable characteristics, for each firm in the sample we use a probit model. Since the choice of the observable covariates in the propensity score model must satisfy the unconfoundedness assumption, the selection of covariates is crucial. All the important variables that influence both the participation decision and the outcome variables should be included. Hence, both economic theory and the policy setting must be used as a guide. In addition, only variables that are unaffected by participation should be included in the model. To ensure this, we choose variables that are either fixed over time, or measured before participation.

In our study, the propensity scores are measured using data for 2004. The explanatory variables include the amount of fossil-fuel-based energy used by the firm, the stock of tangible capital assets, the firm's turnover, and a dummy identifier for whether the firm belongs to the NACE 40 industries.[13] We enforce a common support or overlap condition. This ensures that any combination of characteristics observed in the treatment group can also be observed among firms in the control group. Balance is achieved and there is a significant overlap in the propensity scores of the treatment and comparison groups (see Table 7).[14]

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[13] NACE 40: Electricity, gas, steam and hot water supply.

[14] Our estimation is carried out in STATA, using the "pscore" procedure developed by Becker and Ichino 2002. Adding option "comsup" to the estimation, we ensure that balancing is achieved. The statistical procedure implemented is extremely demanding in that the balancing property is not rejected only in the case that it

Table 7 Distribution of control and treated entities according to their propensity scores in the panel satisfying the common support condition

Propensity score	Non-ETS firms	ETS firms	Total
0-0.09	261	6	267
0.01-0.149	21	0	21
0.15-0.199	8	3	11
0.20-0.399	12	10	22
0.4-0.599	6	8	14
0.6-0.799	3	4	7
0.8-1	1	10	11
Total	312	41	353

Notes: Seven number of blocks optimally selected, significance level 0.01.

Table 8 presents the results of the propensity score measurement. As expected, firms with higher consumption of fossil fuels and more tangible capital assets are more likely to be included in the EU ETS. Additionally, firms belonging to the NACE 40 industries are also more likely to be engaged in emissions trading. The volume of turnover has a negative and significant effect, albeit only at the 10 per cent significance level.

Table 8 Measurement of propensity scores

Variables	Coef.		Std. err.
Fossil fuel quantity	0.245	***	0.063
Capital	0.538	***	0.152
Turnover	-0.281	*	0.154
NACE 40	1.223	***	0.333
Constant	-4.658	***	0.881
Number of observations	601		
LT χ^2 (4)	150.500		
Prob. > χ^2	0.000		
Pseudo R^2	0.503		

Notes: 1. *** p <= 0.01, ** p <= 0.05, * p <= 0.1.
2. All monetary variables are in natural logarithms.

4.2 Average Effects of the EU ETS on ETS Firms

holds for every component of the conditioning vector (see Becker and Ichino 2002 for details). Additional details on the procedure and the complete test results are available from the authors upon request.
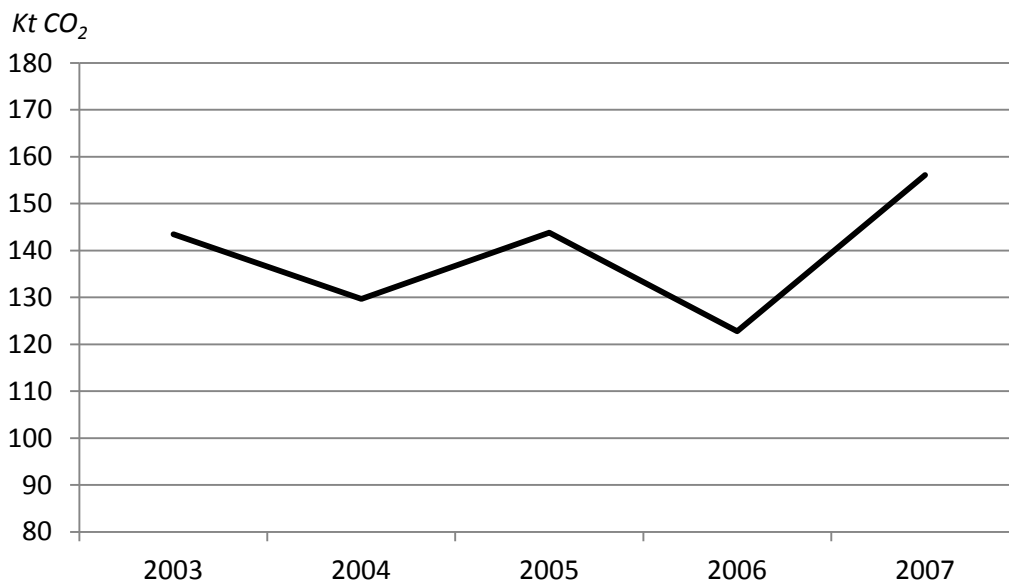
This subsection reports the results of the Kernel and NN matching specifications reflecting the EU ETS impacts. Although the European Emissions Trading Directive was ratified in October 2003, the Lithuanian NAP was approved only in the second half of 2004. Therefore, we use the year 2004 as the pre-treatment year. The outcome variables in the year 2004 are then compared with their counterparts in subsequent years (2005, 2006, 2007, 2008, 2009 and 2010[15]). To better understand the dynamics of the effects, we also compute year-on-year changes. Treatment effects are calculated using a "levels" specification.

Total CO_2 emissions and CO_2 intensity

As the primary goal of the EU ETS is the reduction in absolute GHG emissions, the first question to be explored is whether the EU ETS effected any significant changes in total CO_2 emissions. Figure 2 illustrates the evolution of average CO_2 emissions among ETS firms between 2003 and 2007. Emissions hovered around the pre-treatment average well into Phase I of the ETS, before increasing in 2007. The results from our matching estimation show that these dynamics are not peculiar to ETS firms, but are rather mirrored by comparable firms outside of the treatment group. The results in Table 9 shows that changes over time in CO_2 emissions among ETS firms, where not significantly different in a statistical sense from changes that occurred among firms in the control group. We can conclude that, in terms of overall CO_2 emissions, the introduction of the EU ETS did not significantly affect the behaviour of ETS firms, relative to non-ETS ones. Given that Lithuanian's ETS firms were significantly over-allocated in the first trading periods, and that the price of allowances was already very low by the time allowance trading started to take place in earnest, these finding are hardly surprising.

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[15] Some of the outcome variables, most notably CO_2 emissions, are only available until 2007.

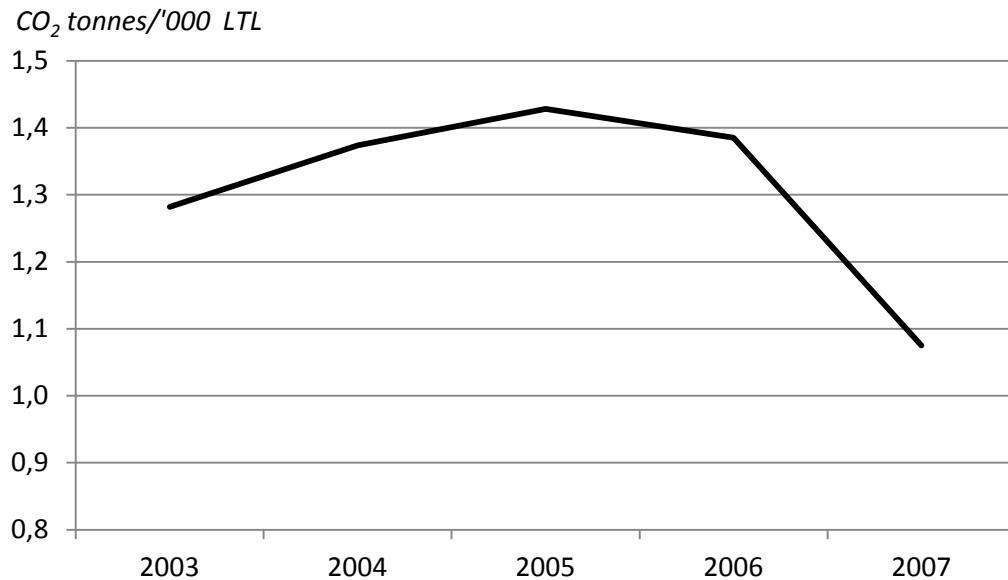**Figure 2 Average CO$_2$ emissions of ETS firms, 2003-2007**

Kt CO$_2$

Source: The authors' calculations from LS data.

These absolute measures, while interesting from the point of view of the environmental integrity of the policy, do not allow us to discriminate between changes in production levels and other adjustments the firms might have made, for example, in terms of their fuel mix or their production technologies. To gain some insight into this second group of factors, we next look at changes in CO$_2$ intensity, measured as the ratio of CO$_2$ emissions over turnover.

Figure 3 shows that, contrary to the trendless emissions path, the emissions intensity of turnover for ETS firms in our sample continued to creep up until 2005, started decreasing in 2006 and fell markedly in 2007. Our matching exercise (see Table 9) confirms this development. In particular, the year-on-year changes confirm the information derived from the previous picture, and inform us that these changes were not significantly different from the behaviour of non-ETS firms, with the exception of the marked reduction in 2007, which is significantly larger than the comparable change for non-ETS firms. Thus, ETS firms seem to have used the first years of the scheme operation to (slowly) learn how to improve on their environmental efficiency, possibly opting to reduce their use of the most CO$_2$ intensive

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fuels, [16] purchasing electricity rather than self-generating, and investing in cleaner technology.

Figure 3 Average CO$_2$ emissions intensity of ETS firms, 2003-2007

Source: The authors' calculations from LS data.

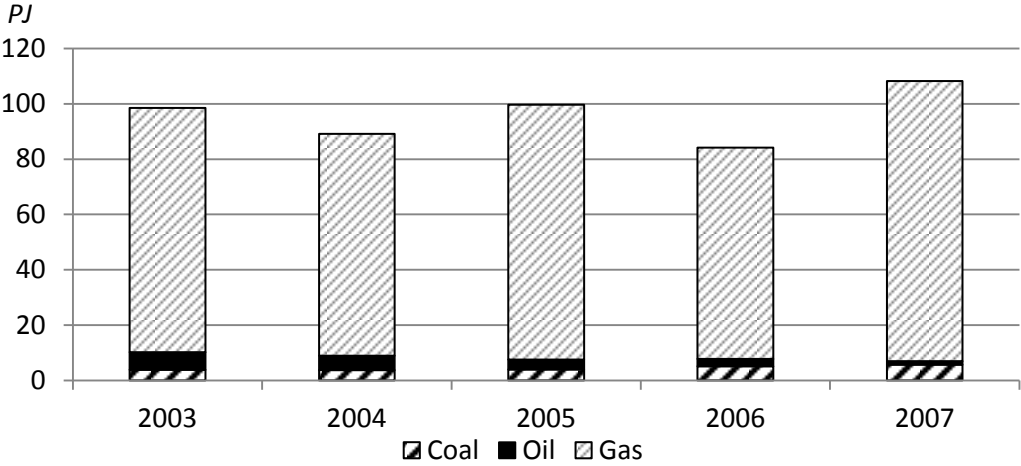*Fuel mix and electricity purchase*

To investigate which of these strategies have been followed by Lithuanian ETS firms, we start by looking at purchases of fossil fuels by the ETS firms in our sample.

As expected, the vast majority of fossil-fuel based energy generation in Lithuanian is based on natural gas, with coal and oil distant second and third. Figure 4 illustrates that the share of oil has been consistently decreasing over time, while coal has increased slightly. This is suggestive of a progressive shift away from expensive oil into cheaper coal and cleaner gas.

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[16] These results are in line with the existing literature on fuel-switching, see e.g. Pettersson, Söderholm, and Lundmark (2012).

The increased reliance on gas by ETS firms is likely to have been the result of the need to compensate for the decrease in electricity output following the closure of Unit 1 of the Ignalina NPP on 31 December 2004. The increase, however, proved to be not as large as it had been previously feared. The natural gas price increase, naturally led to a rise in energy production costs, thus encouraging electricity imports from Russia and Estonia rather than domestic production (Štreimikiene 2008). We find a confirmation of this hypothesis by looking at the increase in electricity purchases by ETS firms over the period 2005-2007 (see Figure 5).

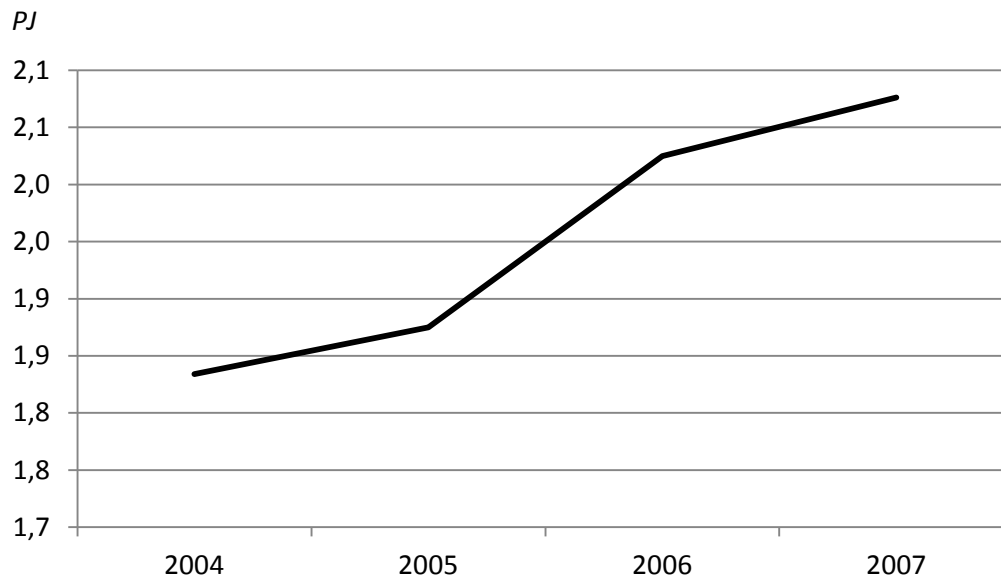**Figure 4 Total purchase of fossil fuel inputs by ETS firms, 2003-2007**

Sources: The authors' calculations from LS data.

This shift away from CO_2-intensive energy carriers into natural gas, and from fossil-based generation into imports can certainly explain the decrease in CO_2 intensity discussed above. We next look at the role of investment in this process.

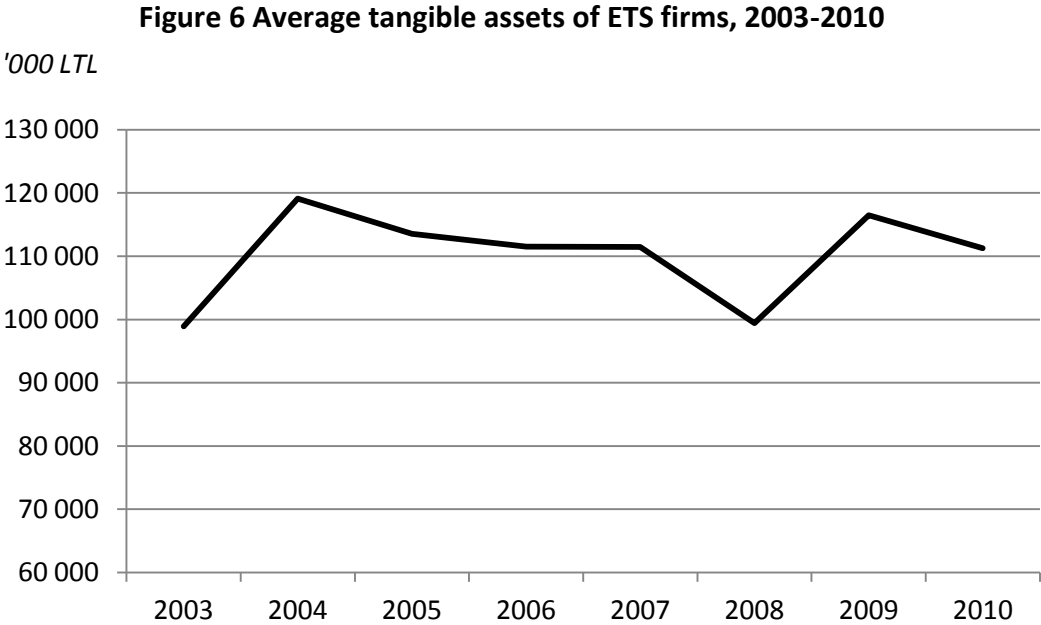**Figure 5 Total purchase of electricity by ETS firms, 2004-2007**

PJ

2,1

2,1

2,0

2,0

1,9

1,9

1,8

1,8

1,7

2004   2005   2006   2007

Sources: The authors' calculations from LS data.

Investment

We now ask the question whether Lithuanian ETS firms invested in new technology following

the commencement of carbon trading in 2005, and whether their behavioural change can be

attributed to the EU ETS. The empirical literature in this area is very scant. Using a survey of

Irish ETS firms over the period 2005-2008, Jaraitė, Convery, and Di Maria (2010) find

suggestive evidence that ETS firms started investing to improve their carbon performance

and achieve compliance under the (perceived) tight Irish permits allocation, already in

preparation of the first phase. Anderson, Convery, and Di Maria (2010) use the same Irish

survey data and find that the EU ETS has influenced the way investments in capital and

infrastructure are planned in almost half of the surveyed firms. They also report that during

the first phase there was a significant amount of technology adoption. Indeed, 50 per cent of

the Irish firms in their sample report employing some form of new machinery or equipment

that contributed to decreasing their CO_2 emissions. Löfgren, Wråke, Hagberg, and Roth

(2013), on the other hand, fail to find any statistically significant impact of the EU ETS on the

investment decision of regulated Swedish firms. Their focus is, however, slightly different

from the papers above, as they only analyse investment in carbon mitigating technologies in a sample of Swedish firms between 2002 and 2008. Our data do not include investment data per se, but we have information on each firm's total tangible capital assets over time. In what follows, we use changes in these assets as a proxy for net capital investment.

Figure 6 shows that the average value of tangible assets among ETS firms in our sample declined steadily throughout the first phase. Thus, it seems unlikely that Lithuanian firms improved their carbon efficiency due to the introduction of new technology.

Figure 6 Average tangible assets of ETS firms, 2003-2010

'000 LTL

Sources: The authors' calculations from LS data.

The figure, together with the results reported in Table 9, indicate that this trend was, however, reversed in 2009, and that this change is exclusive to ETS firms in our sample.

These results are consistent with the view that the introduction of the EU ETS did cause the retirement of old and less efficient tangible assets during the first trading years. In the second phase, instead, the evidence indicates that ETS firms started investing in new capital equipment. One factor that might have led to the 2010 increase is the significant legislative change that took place in 2009. On July 7, 2009 the Lithuanian Parliament passed law XI-329

(Seimas of the Republic of Lithuania 2009), which limited the possibility to recycle revenues from the sale of EUAs. The law in fact mandates that all revenues received from the sale of EUAs should be earmarked to be spent on environmental measures.
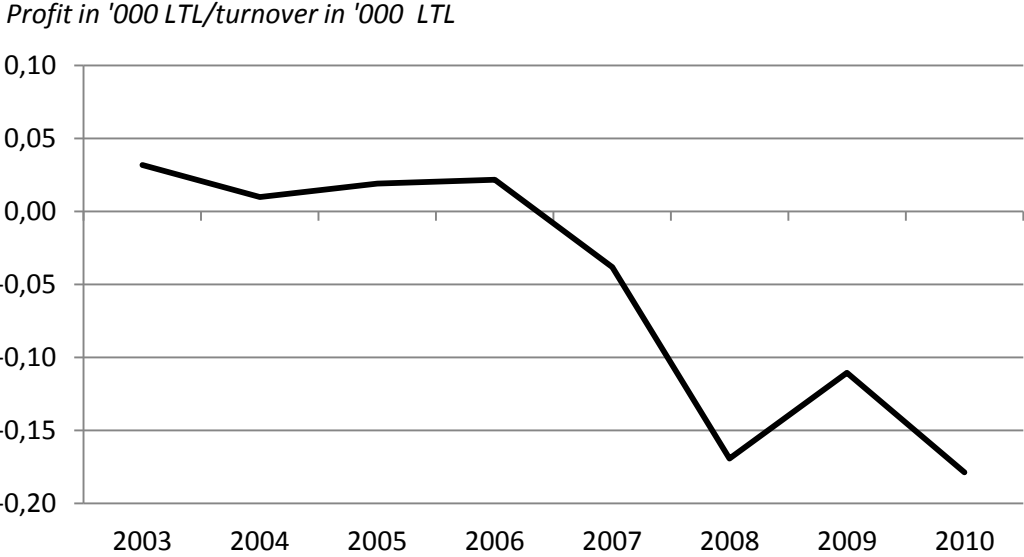
Profitability

The final part of our analysis focuses on assessing the effect of the EU ETS on Lithuanian ETS firms' profitability. Indeed, one of the main concerns raised by the introduction of the EU ETS was the possible deterioration of the competitive position of those ETS sectors most exposed to international competition. It is clear, however, that some of the concerns related to profitability would be alleviated by the fact that within the EU ETS permits are grandfathered, i.e. allocated for free to firms in the EU ETS. In this case, each entity is faced with a clear trade-off between using the permits for compliance purposes (and incurring the opportunity cost of the foregone sale) and selling them on the market (and incurring the cost of abatement). It is this trade-off that generates abatement incentives for efficient firms, who then benefit from the proceeds of the sale of the excess allowances. Revenues from the sale of EUAs are potentially large, and may help bolster the profitability of firms, especially in sectors and countries that received a generous allocation of permits. As discussed in Section 2, Lithuanian firms in all sectors were very generously allocated, and, despite the price collapse, benefited from the sale of EUAs to foreign entities (See Table 3).

Our dataset contains several profit measures, based on financial accounting including gross profit (profit from the main production activities), and profit before tax (profit that takes into account net income from other activities). Although there are as yet no approved accounting standards on how the EUAs should be treated in financial statements, it is recommended to treat them as intangible assets (Rimašauskas 2009). Hence, the net income from

buying/selling EUAs should be recorded among the net income from the other activities. As a consequence, we choose to analyse the relative profit before tax, which is measured as profit before tax over turnover. In what follows, we simply refer to this measure as "profit".

Figure 7 Average profitability of ETS firms, 2003-2010

Profit in '000 LTL/turnover in '000 LTL

Sources: The authors' calculations from LS data.

The average profitability among ETS firms in our sample (Figure 7) and the matching results presented in Table 9 show that ETS firms in Lithuania do not seem to have suffered from their membership of the emission trading scheme in the early stages of the programme. Our results suggest, however, that they might have become less profitable in both 2009 and 2010. The year-on-year changes are similar but with slightly higher significance already in 2007 and 2008. These findings are not surprising, given the amount of over-allocation enjoyed by Lithuanian ETS firms in the first trading phase. The results are also consistent with the findings of Ellerman and Trotignon (2009) that ETS firms in Lithuania were able to monetise their EUA surplus in the first trading period. As discussed in Section 2, ETS firms in Lithuania exported most of their unused allowances in 2007, but the highest revenue was earned in 2006 (see Table 2). This might explain the dip in 2007. Subsequent drops might

instead be explained by the Lithuanian second period allocation being much tighter than the first one.

In essence, our results run counter the statement that the EU ETS exerted a drag on ETS firms' competitiveness and profitability, at least in the context of our case study. In addition to that, although the available data do not allow us to fully understand the pass-through of opportunity costs, we believe that the above findings do not support the hypothesis that costs have been passed through to consumers. At least four reasons can explain it. Firstly, if there had been the pass-through of the opportunity costs into final consumer prices, we would have observed a persistent EU ETS effect on ETS firms' profits. The second reason relates to structure of the markets in which ETS firms operate. ETS firms operating outside the power generating sector, e.g. in the glass, ceramics, refining and food sectors, are more exposed to domestic and international competition, and thus have limited latitude to pass-through opportunity costs. Thirdly, as most of the Lithuanian firms in the EU ETS had more allowances than they needed, they might not have perceived the full opportunity cost of the freely allocated allowances. Finally, in Lithuania energy end-user prices were regulated in the first trading period and beyond, implying that, in the power-generating sector, firms could not have adjusted end-user prices to CO_2 price fluctuations. Nevertheless, a more detailed investigation of these effects would form an interesting topic for future research.

Testing the common-trends assumption

Our analysis relies on the important assumption that the trends in the outcome variables over time should be the same across the ETS and non-ETS firms in our sample. Given the systematic differences in firm size between ETS and non-ETS firms, it is very important to test whether this assumption holds for our data sample. Since we have only two years of the

pre-treatment data, we run a so called placebo DID matching test for those two years (2003 and 2004). In this test, we treat the year 2003 as a pre-treatment year and the year 2004 – as a treatment year. The results[17] of the placebo DID matching test show that there are no statistical differences in the outcome variables (namely, CO_2 emissions, CO_2 emission intensity, tangible capital assets and profitability) between the treatment and control groups for 2003-2004. This suggests that the pre-ETS trends in the outcome variables are the same for the ETS and the non-ETS firms in our sample. As they are the same before the EU ETS was implemented, it will lend some support for the assumption that they are the same after the EU ETS started. In addition to that, these results might indicate that expectations regarding the introduction of the EU ETS were not realised before the year 2005.

5. Conclusions

In this paper, we presented new evidence on the effects of the EU ETS on participating firms. In particular, thanks to the features of our dataset, we were able to assess the impact of the EU ETS directly on CO_2 emissions and their intensity at the firm level, and to study the behaviour of ETS firms as refers to their investments and profitability. Our results indicate that the EU ETS overall did not cause reduction in CO_2 emissions over the whole first trading period. This is understandable, due to the marked over-allocation of the installations in our dataset. We do observe, however, that CO_2 emission intensity decreased between 2006 and 2007, albeit slightly. Unfortunately, the available data do not allow us to investigate whether this decrease was a one-off effect or continued in the second phase of the EU ETS. We also

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[17] Due to space constraints, the results of this test are not reported here. They can be provided by the authors upon request.

find that Lithuanian ETS firms shifted out of expensive energy carriers, like oil and gas, into coal, which remained competitive due to the low price of allowances after 2006. We argue that two factors external to the participation in the ETS, namely the closing of the first reactor of the Ignalina NPP and the high gas prices, led ETS firms in Lithuania to increase their imports of cheaper electricity from neighbouring countries, causing a possible degree of carbon leakage.

Although the EU-wide emission trading system did not seem have encouraged firms to mitigate their CO_2 emissions in the short-run, our analysis suggests that this policy induced the retirement of old (and less efficient) capital stock during the first trading years, and lead to some additional investments into new capital equipment from 2010. The latter effect was probably compounded by the introduction of law XI-329 (Seimas of the Republic of Lithuania 2009), which required the earmarking of allowance sales' revenues for environmental investments. The injection of new, likely more efficient, capital into the existing Lithuanian capital stock suggests that more substantial emission reductions are to be expected in the near future when capital is fully operational.

In terms of economic effects, our results indicate that the EU ETS did not represent a drag on the profitability of Lithuanian ETS firms. This finding, while derived from a small sample of EU ETS firms, is nevertheless consistent with the analyses of, for example, Ellerman, Convery, and de Perthuis (2010), and contributes to alleviate the competitiveness concerns raised by many industry representatives. At the same time, our findings do not support common speculations that the generous permit allocation generated huge windfall profits for the largest polluters.

Overall, our results lend support to the idea that the stringency of the first two phases of the

EU ETS was modest at best, as we find that the EU ETS made very little difference in terms of

the environmental and economic performance of the firms involved in the scheme.

Table 9 Effects of the EU ETS participation – environmental and economic outcome variables

Year	2005		2006		2007		2008		2009		2010	
Method	NN	Kernel	NN	Kernel	NN	Kernel	NN	Kernel	NN	Kernel	NN	Kernel
Outcome: Changes compared to 2004												
CO_2 emissions (kt)	15.6	17.2	-4.0	-2.6	29.4	30.4	-	-	-	-	-	-
	(16.0)	(14.6)	(21.4)	(24.6)	(40.0)	(46.8)						
CO_2 emission intensity (t/000' LTL)	0.017	0.108	-0.004	0.057	-0.212	-0.174	-	-	-	-	-	-
	(0.149)	(0.144)	(0.182)	(0.120)	(0.234)	(0.218)						
Tangible capital assets (000' LTL)	-268294*	-279182**	-231511*	-241331**	-205228*	-212534**	-236077**	-243133**	-238193*	-245108*	138267*	147359**
	(167868)	(152869)	(158402)	(142307)	(124378)	(123191	(136610)	(129401)	(162769)	(153047)	(89324)	(86612)
Profitability (000'LTL/000' LTL)	0.046	0.071	0.045	0.056	-0.022	-0.002	-0.119	-0.112	-0.116*	-0.092	-0.178*	-0.177*
	(0.089)	(0.075)	(0.053)	(0.048)	(0.063)	(0.049)	(0.102)	(0.101)	(0.084)	(0.085)	(0.123)	(0.130)
Outcome: year-on-year changes												
CO_2 emissions (kt)	15.6	17.2	-19.6	-19.8	33.4	33.0	-	-	-	-	-	-
	(13.6)	(14.3)	(18.6)	(14.4)	(32.9)	(33.0)						
CO_2 emission intensity (t/000'LTL)	0.017	0.108	-0.021	-0.051	-0.208*	-0.232*	-	-	-	-	-	-
	(0.168)	(0.142)	(0.129)	(0.117)	(0.145)	(0.144)						
Tangible capital assets (000'LTL)	-268294*	-279182**	36783*	37851**	26284*	28797**	-30849**	-30599**	-2116	-1975	376460*	392466**
	(193011)	(160858)	(23768)	(21504)	(17504)	(16861)	(15774)	(14696)	(23362)	(22164)	(267101)	(185823)
Profitability (000'LTL/000'LTL)	0.046	0.071	-0.001	-0.016	-0.067**	-0.057**	-0.097*	-0.110**	0.003	0.021	-0.062	-0.085*
	(0.077)	(0.067)	(0.065)	(0.058)	(0.037)	(0.028)	(0.075)	(0.058)	(0.144)	(0.141)	(0.058)	(0.059)

Notes:
1. ***p <=0.01, **p <= 0.05, *p <= 0.1, the p-values are calculated using one-tailed t-tests.
2. The bootstrapped standard errors are in the parentheses.
3. All monetary variables are in real terms.
4. There are 41 ETS firms in the treated group.
5. Kernel matching is based on 312 firms in the control group.
6. NN matching with replacement is based on 22 firms in the control group.

References

Abrell, J., A. N. Faye, and G. Zachmann. 2011. Assessing the Impact of the EU ETS using Firm Level Data. In *Working Papers of BETA* Bureau d'Economie Théorique et Appliquée, UDS, Strasbourg.

Anderson, B., and C. Di Maria. 2011. "Abatement and Allocation in the Pilot Phase of the EU ETS." *Environmental and Resource Economics* 48 (1):83-103.

Anderson, B. J., F. J. Convery, and C. Di Maria. 2010. Technological Change and the EU ETS: the Case of Ireland. In *The 4th World Congress of Environmental and Resource Economists* Montreal, Canada.

Anger, N., and U. Oberndorfer. 2008. "Firm Performance and Employment in the EU Emissions Trading Scheme: An Empirical Assessment for Germany." *Energy Policy* 36 (1):12-22.

Becker, S. O., and A. Ichino. 2002. "Estimation of average treatment effects based on propensity scores." *The Stata Journal* 2 (4): 358-377.

Böhringer, C., T. Hoffmann, A. Lange, A. Löschel, and U. Moslener. 2005. "Assessing Emission Regulation in Europe: An Interactive Simulation Approach." *The Energy Journal* 26 (4): 1-22.

Caliendo, M., and S. Kopeinig. 2008. "Some Practical Guidance for the Implementation of Propensity Score Matching." *Journal of Economic Surveys* 22 (1):31-72.

Chan, H. S., L. Shanjun, and F. Zhang. 2012. Firm Competitiveness and the European Union Emissions Trading Scheme. Available at SSRN: http://ssrn.com/abstract=2167298.

Delarue, E. D., A. D. Ellerman, and W. D'Haeseleer. 2010. "Short-term CO2 abatement in the European power sector: 2005-2006." *Climatic Change Economics* 1 (2):113-133.

Demailly, D., and P. Quirion. 2008. "European Emission Trading Scheme and Competitiveness: A Case Study on the Iron and Steel Industry". *Energy Economics* 30 (4): 2009–2027.

Ellerman, A. D., and B. K. Buchner. 2008. "Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005-2006 Emissions Data." *Environmental and Resource Economics* 41 (2):267-287.

Ellerman, A.D., F.J. Convery, and C. de Perthuis. 2010. *Pricing Carbon: the European Union Emissions Trading Scheme*. Cambridge, UK: Cambridge University Press.

Ellerman, A.D., and R. Trotignon. 2009. "Cross-border trading and borrowing in the EU ETS." *The Energy Journal* 30 (2):53-77.

Heckman, J. J., H. Ichimura, J. Smith, and P. E. Todd. 1998. "Characterizing Selection Bias Using Experimental Data." *Econometrica* 66 (5):1017-1098.

Heckman, J. J., H. Ichimura, and P. E. Todd. 1997. "Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme." *Review of Economic Studies* 64 (4):605-654.

Imbens, G. 2004. "Nonparametric estimation of average treatment effects under exogeneity: a review." *Review of Economics and Statistics* 86 (1): 4–29.

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

Kemfert, C., M. Kohlhaas, P. T. Truong, and A. Protsenko. 2006. "The Environmental and Economic Effects of European Emissions Trading." Climate Policy 6(4): 441-55.

Linden, M., M. Mäkelä and J. Uusivuori. 2013. "Fuel Input Substitution under Tradable Carbon Permits System: Evidence from Finnish Energy Plants 2005–2008." The Energy Journal 34 (2): 145-167.

Löfgren, A., M. Wråke, T. Hagberg, and S. Roth. 2013. The Effect of EU-ETS on Swedish Industry's Investment in Carbon Mitigating Technologies. In *Working paper*: Göteborg University, Department of Economics.

McGuinness, M., and R. Trotignon. 2007. Technical Memorandum on Analysis of the EU ETS Using the Community Independent Transaction Log. In Working paper: Centre for Energy and Environmental Policy Research, MIT, Boston.

National Audit Office of Lithuania. 2008. Apyvartinių Taršos Leidimų Paskirstymo ir Prekybos Sistemos Vertinimas. In *Valstybinio audito ataskaita*: National Audit Office of Lithuania.

Neuhoff, K., K. Keats, and M. Sato. 2006. "Allocation, incentives and distorsions: the impact of EU ETS emissions allowance allocation to the electricity sector". Climate Policy, 6 (1):73‑91.

Pettersson, F., P. Söderholm, and R. Lundmark. 2012. "Fuel switching and climate and energy policies in the European power generation sector: a generalized Leontief model." *Energy Economics* 34 (4): 1064-1073.

Rimašauskas, S. 2009. Apyvartinių Taršos Leidimų Apskaita. Deloitte Lietuva.

Rosenbaum, P. R., and D. B. Rubin. 1983. "The Central Role of the Propensity Score in Observational Studies for Causal Effects." *Biometrika* 70 (1):41-55.

Rubin, D. B. 1990. "Formal Modes of Statistical Inference for Causal Effects." *Journal of Statistical Planning and Inference* 25:279-292.

Seimas of the Republic of Lithuania. 2009. Klimato kaitos valdymo finansinių instrumentų įstatymas. In *XI-329*. Vilnius.

Smith, J. A., and P. E. Todd. 2005. "Does Matching Overcome LaLonde's Critique of Nonexperimental Estimators?" *Journal of Econometrics* 125 (1-2):305-353.

Štreimikiene, D. 2008. Lithuania's Perspective on EU ETS in 2005-2007. Lithuanian energy institute.

Venmans, F. 2012. "A literature-based multi-criteria evaluation of the EU ETS." *Renewable and Sustainable Energy Reviews* 16 (8):5493-5510.

Widerberg, A., and M. Wråke. 2009. The impact of the EU emissions trading system on CO2 intensity in electricity generation. In *Working paper*: Göteborg University, Department of Economics.

Yu, H. 2011. The EU ETS and Firm Profits: An Ex-post Analysis for Swedish Energy Firms. Department of Economics, Uppsala University.

Zapfel, P. 2007. "A Brief But Lively Chapter in EU Climate Policy: the Commission's Perspective." In *Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness*, edited by A. D. Ellerman, B. K. Buchner and C. Carraro. Cambridge University Press.

Zhang, Y.-J., and Y.-M. Wei. 2010. "An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect." *Applied Energy* 87 (6):1804-1814.

Appendix: The conversion of fuel purchase into CO_2 emissions

CO_2 emissions are produced when carbon based fuels are burned. Therefore we produce our CO_2 emissions estimates based on the amount of fossil fuels purchased (unfortunately, the data on fossil fuel use is not available) and on the carbon content of fuels. The calculation of CO_2 emissions can be broken down into three steps: (1) calculate fuel consumption in original units by dividing nominal fossil fuel purchases by nominal fossil fuel prices (see Table A1); (2) convert fuel units to common energy units by using specific net calorific values (see Table A2); and (3) multiply energy units by CO_2 emission factors to compute carbon content (see Table A3).

The LS data set provides only three types of fossil fuel purchases: coal, petroleum products and natural gas. As it is unknown what specific petroleum fuels are covered in the category of petroleum products, crude oil prices, net calorific value and CO_2 conversion factors are used instead.

Table A1 Lithuania's nominal fossil fuel and electricity prices, 2003-07/10

Fuel forms	Unit	2003	2004	2005	2006	2007	2008	2009	2010
Coal	LTL/tonne	133.1	143.6	172.5	165.3	163.2			
Crude oil	LTL/tonne	580.8	635.1	944.3	1303	1212.7			
Natural gas	LTL/1000 m^3	243	229.2	237.2	339.6	468.3			
Electricity (industry)	LTL/kWh	0.2252	0.2295	0.2324	0.2343	0.2602	0.3349	0.3579	0.4335

Sources: Lithuanian Energy Institute and the IEA statistics database.

Table A2 Lithuania's net calorific values of fossil fuels

Fuel forms	Unit	NCV
Coal	TJ/Gg (kilotonne)	25.12
Crude oil	TJ/Gg (kilotonne)	42.3
Natural gas	GJ/1000 m^3	33.49

Sources: Lithuanian Energy Institute and IPCC Guidelines for National Greenhouse Gas Inventories.

Table A3 Lithuania's CO_2 emission factors

Fuel forms	Unit	CO_2 emission factors
Coal	Kg/GJ	95
Crude oil	Kg/GJ	78
Natural gas	Kg/GJ	56.9

Source: The Ministry of Environment of the Republic of Lithuania.

The main uncertainty about the CO_2 emission estimates arises from the fact that the available fossil fuel purchase data are aggregated. That is we cannot explicitly determine what share of fossil fuel purchase is used for combustion and processes that are accounted by the EU ETS. In this regard, the CO_2 emission estimates are upward biased. Secondly, the data correspond to fuel purchase rather than fuel use. This might introduce some timing issues of emission release, especially if firms have a sufficient capacity to store fossil fuels. In our analysis we assume that fossil fuel purchase materializes into CO_2 emissions in the same year. Thirdly, the purchase data are available on a firm level rather than on an installation level, meaning that if a firm has other, smaller installations which are not in the EU ETS, we might get higher emissions then the ones included in the EU ETS. Again, in this respect we will get the upward biased CO_2 estimates. All these suggest that the results for the estimates that involve CO_2 emissions should be interpreted with caution, and that signs of the econometric estimates should be preferred over the magnitudes.