Replication Study of "Coase and cap-and-trade" (Zaklan 2023)

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Abstract

Zaklan (2023) examines the coasean independence property in the EU-ETS. To test this property, the author studies whether emissions are independent from the free allowance allocation. Some allowances were given for free to all EU Member States until 2012. From 2013 allowances were fully auctioned, apart in 10 countries that were granted an exception to continue to give free allowances to their firms. Treated firms are firms located in countries that do not receive free allowances anymore. Control firms are firms located in countries that continue to receive free allowances. The main analysis is led at the firm level using annual data from 2009 to 2017. Two way fixed effects estimators are combined with 1 to 1 matching to estimate the impact of the treatment on firms' emissions. The main claim is that the independence property holds overall and on large emitters. Moreover, there is suggestive evidence that the independence property does not hold for small emitters. The study is reproducible. The STATA code runs smoothly and enough information is available to reproduce the main results using the R software. We apply different robustness checks on: the matching strategy, the specification, the level of clustering, the definition of the treatment and the definition of the cutoff that differentiates small and large emitters. We generally align with the author's assertion that the independence property is not rejected both overall and for large emitters. However, in most instances, we do not confirm the suggestive evidence that the independence property is rejected for small emitters. Moreover, the change in the definition of the treated firms is a robustness check to be considered separately as it leads to sign reversal in most regressions.

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1 Introduction

Zaklan (2023) examines the coasean independence property in the EU-ETS. To test this property, the author studies whether emissions are independent from the free allowance allocation. Some allowances were given for free to all EU Member States until 2012. From 2013 allowances were fully auctioned, apart in 10 countries that were granted an exception to continue to give free allowances to their firms. Treated firms are firms located in countries that do not receive free allowances anymore. Control firms are firms located in countries that continue to receive free allowances. The main analysis is led at the firm level using annual data from 2009 to 2017.

To measure emissions, the author uses annual emissions data from the European Union transaction log Dataset projects (Jaraitė et al. 2016). Data on installations from the category 35 "Electricity, gas, steel and air conditioning supply" are aggregated at the firm level for the main estimations.

The main claim is that the independence property holds overall and on large emitters. Moreover there are suggestive evidence that the independence property does not hold for small emitters. Those results are provided Table 3 and 4 in the article.

Table 3 presents estimations without distinction between small and large emitters. Two-way fixed effects (TWFE) estimators are used to estimate the impact of the treatment (difference-in-differences estimations). Analyses on the full sample in columns (1) to (3) suggest that treated firms emit significantly less than control firms. As indicated p.546, "In the full sample, switching from free allocation to full auctioning is estimated to significantly decrease firms' emissions in all three specifications by between 9.5 percent and 14.4 percent." In columns (4) to (6) TWFE estimators are combined with 1 to 1 nearest neighbor propensity score matching with replacement to estimate the impact of the treatment on firms' emissions. As indicated p.546, point estimates are of the same sign as in the full sample analysis, but neither of the point estimates are statistically significant.

Table 4 tests the idea that the coasean independence property holds on large emitters, but not on small ones. This means that the end of the free allocation has an effect on the emissions of small firms, but not large ones. To define small and large emitters, the author uses the distribution of emissions in 2009. Those in below the 25^{th} percentile of emissions in the treated group are considered as small and those above as large emitters. The same procedure is used to define small and large emitters in the control group. The cutoff is therefore different for treated and control firms, as it is based on the distribution of 2009 emissions in each treatment group. Then TWFE are combined with 1 to 1 nearest neighbor propensity score matching

with replacement to estimate the impact of the treatment on firms' emissions. As stated on page 536, "the propensity score is estimated by regressing the treatment indicator on the average of installations' log pretreatment emissions, i.e., emissions during the period 2009–2012, using a logit model." The author find that small emitters decrease their emissions by 19% due to the loss in allocation. In contrast, no statistically significant effect of the loss in allocation is found for large emitters.

In this replication report we focus on the preferred specifications of the author whose results are presented in column 2 of Table 3 p.546 and column 5 Table 4 p.548 in the original study. As pointed by the author, those specifications are the most demanding ones, as they control for both firm and year fixed effects, as well as additional time-varying covariates.

In Section 2, we discuss the reproducibility of the result using the STATA and R softwares. In Section 3, we propose several robustness checks : changing the level of clustering, the specification, the definition of matches, the definition of treated, and the criteria used to distinguish small and large emitters.

2 Reproducibility

In this section, we discuss the reproducibility of the paper's main results. We first reproduced the results using the author's STATA code and then transcribed the code to R in order to attest that the results are robust to the use of another statistical software. We did not uncover any error in the author's code and were able to reproduce the results smoothly.

2.1 Baseline Firm-Level Results (Table 3 in original study)

Zaklan (2023) provides firm-level estimates of the impact of the switch from free allocation to full auctioning in Table 3. In our attempt to reproduce these results, we found no coding errors in the author's code and were able to easily replicate the table using STATA. We further validated these results by replicating the matching procedure and the estimation in R, uncovering no coding error in the process.

2.2 Small and Non-small Emitters (Table 4 in original study)

The paper introduces a distinction between small and large emitters and tests the coasian independence property on both types of firms in Table 4. As explained in Section 1, Table 4 focuses on the matched sample. We were able to reproduce the results smoothly using the author's STATA code and successfully re-coded the procedure in R, finding the same results.

3 Replication (Robustness Replicability)

3.1 Baseline Firm-Level Results (Table 3 in original study)

3.1.1 Clustering standard-errors at the country-level

Since several firms can be located in the same country, we reran main FE regression models from the original study (regressions on the full sample, columns (1) to (3) Table 3) using clustered standard errors at the country level, rather than firm level. It is also the classic recommendation of Moulton (1990) to cluster standard errors at the level of the treatment, here the country-level. Results are displayed in Table 1. They suggest that emissions are independent of changes in allocation policy when we look at all 385 firms in the sample. We therefore agree with the main claim of the authors and show that even without implementing a matching procedure, only by clustering standard errors at a more relevant level, the effect of the treatment becomes non-significant on the full sample. The clustering at the country level leads and inflation of standard errors. It becomes hard to say that the independence assumption holds overall, one can just say that it is not rejected, coefficients being imprecisely estimated.

3.1.2 Specification including treatment-by-year variables

One concern with the author's main claim that emissions are independent of changes in allocation policy on average over the studied period is that this result may not hold when looking at dynamic annual effects. We check this by adding by-year interactive terms to the main FE regression models presented in columns (1) to (3) of Table 3 of the original study, keeping 2009 as the reference year. Results are displayed in Table 2. Columns (1) and (2) show results with standard errors clustered at the firm level, and columns (3) and (4) with clustering at the country level. Overall, they show a statistically insignificant link between emissions and treatment for the years 2010, 2011 and 2012, regardless of the level of clustering chosen for the standard errors, which confirms that the parallel trend hypothesis holds for this period. However, we observe a statistically significant effect at the usual significance thresholds when looking at years 2014 and 2015. The effect remains significant when clustering at the country level. Results for years 2016 and 2017 are not significant. Thus, although we are not able to conclude that there is a significant link between emissions and allocation policy on average over the period, we cannot exclude its existence for 2014 and 2015. This result is consistent with Figure 5 of the original paper, in which the author displays dynamic year-by-year effects for the matched sample and find a significant negative effect in 2014.

3.1.3 Alternative definition of matches

We tested the sensitivity of the results to the matching procedure. We first applied the nearest-neighbor estimator like the author but using a different set of covariates: instead of using the average level of emissions, we include the annual levels of emissions over the pre-treatment period. We then applied the kernel matching estimator. Results are presented in Table 3. They are in line with the author's results, which did not highlight any result significantly different from zero.

3.1.4 Alternative definitions of treated

In the paper, treated firms are defined as those located in countries that have changed their allocation system from free allocation to full auctioning. The author states, however, that firms located in the treatment countries still receive free allowances for cooling or heating generation after 2012 (Footnotes 9, 26).[1]

Our aim was to reproduce paper's Table 3 by using alternative treatment group definitions based on each firm's actual allowance acquisition mode, instead of the firm's location. We do this only for the preferred specifications with firm and year fixed effects: column (2) for the full sample and column (5) for the matched sample. In this section, firm-level data are used, and the matched samples are obtained using the same procedure as in the original paper. All robustness checks presented in this section are done using the R software, as we have attested in section 2.1 that estimators coded in R produce exactly the same results as in STATA.

First, firms are defined as 'treated' if they did not receive any free allocations during the period from 2013 to 2017. The results presented in Table 4 are consistent with the findings of the original study, revealing no significant differences in emissions using a matched sample. For the full sample, we find that firms that did not receive free allowances in the period 2013-2017 emit significantly more than others, whereas in the original study, emissions are found to decrease in the country that switched to auctioning allowances. The 'no free allocation' definition of treated is however quite restrictive, as many firms in the treatment countries continued to receive small amounts of free allowances after 2012 and are considered as part of the control group. In this case, the proportion of treated firms is around 17% of the full sample of firms, instead of 80% in the paper. Therefore, the absence of significant differences in emissions in the matched sample could also be due to the loss of statistical power compared with the original study.

Second, we use the average share of emissions covered by free allocations (share of free allowances) in the period 2013-2017 to define treated firms. We consider thresholds of 5, 10, 15, 25 and 50 percent of emissions covered by free allowances.

[1] Actually, own computations indicate that only 21.4% of treated firms received no free allocation at all in the period 2013-2017.

Similar patterns are observed as for the previous treatment definition. Specifically, firms emit significantly more after the loss of free allocation using the full sample (Table 5), while there are no significant differences between treated and non-treated firms in the matched sample using the 5 and 10 percent thresholds (Table 6). Setting the threshold at a higher share of free allowances leads to significantly higher emissions of treated firms, even in the matched sample. The less restrictive the threshold, i.e. the larger the treated group size, the more significant the difference.

Finally, although most European countries transitioned to full auctioning, the share of free allowances in those countries after 2012 is not zero. As a last robustness test, we propose a definition of treated firms based on the rate at which free allowances allocated to each firm decreased, after the 2012's transition to full auctioning in most European countries. This variable is calculated, for a given firm, from the average amount of free allowances received per year before (S^B) and after (S^A) 2012, such as $-\frac{S^A-S^B}{S^B}$.[2] Firms with reduction rates (1) higher than the $75th$ percentile and (2) higher than the median are defined as treated. Results presented in Table 7 are in line with the original study when the threshold is set at the $75th$ percentile, i.e, treatment induces a significant difference in emissions in the full sample but not in the matched sample. However, in the full sample, the sign is reversed compared to the original study when using the threshold is set at the $75th$ percentile. In addition, we find a significant difference between treated and control firms both in the full sample and in the matched sample when the threshold is set at the median. Again, the less restrictive the threshold, the more significant the difference. As in the previous paragraph, treated firms tend to emit more than controls.

3.2 Small and Nonsmall emitters (Table 4 in original study)

3.2.1 Sensitivity to the definition of small emitters

One of the main claim of Zaklan (2023) is that the coasean independence property holds on large emitters, but not on small emitters (suggestive evidence). To define small and large emitters, the author uses the distribution of emissions in 2009. Those in below the 25^{th} percentile of emissions in the treated group are considered as small and those above as large emitters. The same procedure is used to define small and large emitters in the control group. A first remark is that it leads to use a very different threshold in terms of emissions for the treated and control groups: 40,913 vs. 214,862 tons of CO2 per year.

In this Section, we test the robustness of this result following two approaches:

[2]Note that out of the full sample of 385 firms, seven firms that did not receive any free allowances in the 2009-2012 period are excluded, reducing the full sample size to 378 observations.

(i) we use different percentile to distinguish small and large emitters, (ii) we use different base variables to distinguish small and large emitters.

Using another percentile to define small emitters

We changed the percentile used to distinguish the two groups and rerun the estimations. As a visual inspection of the distribution of emissions do not lead to identify a "natural" threshold to distinguish small and large emitters, and as the choice of the 25^{th} percentile in the paper was not backed up by theoretical or empirical arguments, we tested percentiles from 10 to 40.

The results obtained for this new definition of a small firm are provided in Table 8. Results appear sensible to the percentile used. Using the 25^{th} percentile of the distribution as threshold, Zaklan (2023) finds that small emitters in the treated group emit less CO2 than control firms at the 10% significance level. However, the coefficient is no longer significant when the 20^{th} or 30^{th} percentile is used. Among all percentiles we tested, it is only significant when the 15^{th} or 27^{th} percentiles are used. Note however that when the 15^{th} percentile is used, only two firms remain in the small emitters control group, which indicates that the result is rather fragile.

The results obtained for this new definition of a large firm are provided in Table 9. Using the 25^{th} percentile of the distribution as threshold, Zaklan (2023) finds that emissions from large emitters in the treated group are not significantly different from those of the control firms. This result is robust to the application of the same robustness checks than for the small emitters.

Using different base variables to define small emitters

In the original study, the author used the distribution of 2009 emissions of firms to compute the thresholds. As he used average emissions from 2009 to 2012 to estimate propensity scores in the matching procedure, we chose to use this variable to compute the 25^{th} percentiles. Second, we considered that having a different threshold for the treated and control groups was not driven by strong theoretical arguments. Thus, we use the 25^{th} percentile of the whole sample distribution to define small and large emitters. It leads use to use a unique threshold of 54,919 tons of CO2 per year.

The results obtained for this new definition of a small firm are reported in Table 10. Results when using the 2009-2012 average emissions as a threshold are strikingly similar to those published in the original study (see Col. 1-2). Then, we reran the estimation using a new unique threshold, using the 2009 emissions in Column (3) and the average 2009-2012 emissions in Column (4). Both approaches lead to find very similar thresholds 54919 and 59427 tons of CO2 per year respectively. Thus, they lead to consider the same sample of firms which leads to identical results

in Column (3) and (4). These results are very different from the published ones, with positive and insignificant coefficients (p-value=0.486).

The results obtained for this new definition of a large firm are provided in Table 11. Again we found, in line with Zaklan (2023), no significant results from the sample of large emitters.

3.2.2 Formal test of heterogeneous effect by firm size

Finally, we estimated a FE model which allows us to directly test the heterogeneity of the policy effect, if it exists. This model includes a dummy that takes the value of one for small firms and zero elsewhere, using the definition of small firm chosen by the author; we interacted it with the treatment. Results are reported in Table 12. They do not support the assertion that small firms behave differently from large ones.

4 Conclusion

The main claim of Zaklan (2023) is that the independence property holds overall and on large emitters. Moreover there are suggestive evidence that the independence property does not hold for small emitters.

The study is reproducible. The STATA code runs smoothly and enough information is available to reproduce the main results using the R software.

Overall we find the main claim is robust to several robustness tests but suggestive evidence on small emitters are very fragile. Results are robust to the use of different matching strategies. However, they are not robust to the use of different specifications, to the clustering of standard errors at an alternative level and are very sensible to a change in the cutoff that differentiate large and small emitters. For these robustness checks, we generally align with the authors' assertion that the independence property holds both overall and for large emitters. However, in most instances, we do not observe the rejection of the independence property for small emitters.

When we use an alternative definition of the treatment, meaning that we use the actual quantity of free allowances perceived by firms instead of the country where firms are located to define the treatment, in most cases, regression results lead to reject the independence property, but with sign reversal compared to the original study. We are unable to provide theoretical reasons for this sign reversal. We simply observe that treated firms are very different with this new definition of the treatment.

We concur with the author that his findings, along with those from our replication exercise, call further investigation into the topic, particularly regarding the

behavior of small emitters.

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5 Tables

Table 1: Replication of Table 3 using alternative clustered standard errors

FE regression	Original study (1)	Original study (2)	Original study (3)	Alt. clusters (4)	Alt. clusters (5)	Alt. clusters (6)
1.Auctioning	-0.095**	-0.144***	-0.141***	-0.095	-0.144	-0.141
	(0.040)	(0.045)	(0.045)	(0.084)	(0.085)	(0.083)
	[0.019]	[0.001]	[0.002]	[0.266]	[0.105]	[0.103]
ln(RE)		-0.136*	-0.198***		-0.136	-0.198
		(0.075)	(0.065)		(0.163)	(0.144)
		[0.070]	[0.003]		[0.415]	[0.182]
ln(elec cons)		0.988**	1.735***		0.988	1.735*
		(0.425)	(0.391)		(0.823)	(0.902)
		[0.021]	[0.000]		[0.243]	[0.068]
Net elec exp		0.004***	0.004***		0.004	0.004
		(0.001)	(0.001)		(0.003)	(0.003)
		[0.003]	[0.000]		[0.189]	[0.141]
ln(GDP)		-0.965***	-1.406***		-0.965	-1.406**
		(0.320)	(0.319)		(0.568)	(0.627)
		[0.003]	[0.000]		[0.103]	[0.035]
EUA price			0.001			0.001
			(0.003)			(0.004)
			[0.791]			[0.856]
Coal price			0.013**			0.013
			(0.005)			(0.010)
			[0.014]			[0.213]
Gas price			-0.004*			-0.004
			(0.002)			(0.003)
			[0.061]			[0.172]
cons	12.520***	15.012**	12.634**	12.520***	15.012*	12.634*
	(0.016)	(4.646)	(3.989)	(0.028)	(8.510)	(6.890)
	[0.000]	[0.001]	[0.002]	[0.000]	[0.092]	[0.080]
Observations	3,465	3,465	3,465	3,465	3,465	3,465
Nb of firms	385	385	385	385	385	385

Notes: This table provides the results of FE model regressions using full (unmatched) sample. Robust standard errors are in parentheses, clustered by firm in Col(1)-(2)-(3) and by country in Col(4)-(5)-(6). P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 2: Replication of Table 3 including by-year interactions

FE regression	(1)	(2)	(3)	(4)
1.Auctioning.2010	0.049**	0.018	0.049	0.018
	(0.023)	(0.027)	(0.036)	(0.038)
	[0.035]	[0.514]	[0.189]	[0.647]
1.Auctioning.2011	0.010	0.010	0.010	0.010
	(0.036)	(0.040)	(0.022)	(0.053)
	[0.791]	[0.793]	[0.670]	[0.846]
1.Auctioning.2012	-0.037	-0.062	-0.037	-0.062
	(0.037)	(0.042)	(0.042)	(0.059)
	[0.323]	[0.144]	[0.388]	[0.308]
1.Auctioning.2013	-0.057	-0.108**	-0.057	-0.108
	(0.041)	(0.049)	(0.049)	(0.066)
	[0.172]	[0.026]	[0.259]	[0.115]
1.Auctioning.2014	-0.159***	-0.214***	-0.159*	-0.214*
	(0.056)	(0.068)	(0.088)	(0.108)
	[0.005]	[0.002]	[0.083]	[0.059]
1.Auctioning.2015	-0.153***	-0.233***	-0.153	-0.233*
	(0.056)	(0.073)	(0.104)	(0.129)
	[0.007]	[0.001]	[0.153]	[0.084]
1.Auctioning.2016	-0.044	-0.117	-0.044	-0.117
	(0.054)	(0.069)	(0.095)	(0.110)
	[0.415]	[0.088]	[0.648]	[0.299]
1.Auctioning.2017	-0.037	-0.104	-0.037	-0.104
	(0.062)	(0.074)	(0.111)	(0.113)
	[0.554]	[0.159]	[0.743]	[0.369]
ln(RE)		-0.157**		-0.157
		(0.079)		(0.170)
		[0.047]		[0.367]
ln(elec cons)		0.972**		0.972
		(0.450)		(0.762)
		[0.031]		[0.215]
Net elec exp		0.004***		0.004
		(0.001)		(0.003)
		[0.003]		[0.186]
ln(GDP)		-0.937***		-0.937
		(0.322)		(0.568)
		[0.004]		[0.113]
cons	12.520***	15.041***	12.520***	15.041
	(0.016)	(5.135)	(0.028)	(8.934)
	[0.000]	[0.004]	[0.000]	[0.106]
Observations	3,465	3,465	3,465	3,465
Nb of firms	385	385	385	385

Notes: This table provides the results of an alternative specification for the FE model regressions that include by-year interactive terms, using full (unmatched) sample. Robust standard errors are in parentheses, clustered by firm in Col(1)-(2) and by country in Col(3)-(4). P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 3: Replication of Table 3 using alternative matching procedures

FE regression	Original study (1)	Original study (2)	NNM (alt. cov.) (3)	NNM (alt. cov.) (4)	Kernel matching (5)	Kernel matching (6)
1.Auctioning	-0.066	-0.056	-0.039	-0.029	-0.053	-0.044
	(0.059)	(0.066)	(0.064)	(0.071)	(0.051)	(0.060)
	[0.261]	[0.395]	[0.539]	[0.682]	[0.300]	[0.470]
ln(RE)		0.124		0.265		0.107
		(0.125)		(0.172)		(0.119)
		[0.320]		[0.124]		[0.366]
ln(elec cons)		1.390**		0.725		1.251**
		(0.540)		(0.511)		(0.502)
		[0.010]		[0.157]		[0.013]
Net elec exp		0.002		0.001		0.002*
		(0.001)		(0.002)		(0.001)
		[0.137]		[0.710]		[0.098]
ln(GDP)		-1.043***		-1.008***		-0.930***
		(0.324)		(0.332)		(0.302)
		[0.001]		[0.003]		[0.002]
cons	12.486***	8.608	12.638***	14.559***	12.582***	9.015*
	0.032	5.884	0.036	5.433	0.026	5.228
	[0.000]	[0.144]	[0.000]	[0.008]	[0.000]	[0.085]
Observations	5,112	5,112	4,896	4,896	3,285	3,285
Nb of firms	352	352	340	340	365	365

Notes: This table provides the results of FE model regressions using alternative matched samples. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 4: Replication of Table 3 using alternative definitions of treated firms (1)

Definition of treated	Full sample		Matched samples	
	Original study (1)	No free allocation (2)	Original study (3)	No free allocation (4)
1(Auctioning)	-0.144***		-0.056	
	(0.045)		(0.066)	
	[0.001]		[0.396]	
1(No free allowances)		0.111*		-0.029
		(0.065)		(0.088)
		[0.089]		[0.744]
ln(Renewable energy)	-0.136*	-0.058	0.124	-0.015
	(0.075)	(0.071)	(0.125)	(0.114)
	[0.070]	[0.409]	[0.320]	[0.897]
ln(Electricity consumption)	0.988**	1.724***	1.390**	0.604
	(0.425)	(0.461)	(0.541)	(0.719)
	[0.021]	[<0.001]	[0.011]	[0.403]
ln(GDP)	-0.965***	-0.895***	-1.043***	-1.090***
	(0.320)	(0.293)	(0.324)	(0.365)
	[0.003]	[0.002]	[0.001]	[0.003]
Net electricity exports	0.004***	0.003**	0.002	-0.001
	(0.001)	(0.001)	(0.001)	(0.002)
	[0.003]	[0.013]	[0.137]	[0.716]
Observations	3465	3465	3168	1053
Nb. of firms	385	385	352	117

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms defined as in the original study (columns 1 and 3) and as those that perceived zero free allowances in the period 2013-2017 (columns 2 and 4). Year and firm fixed effects. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 5: Replication of Table 3 using alternative definitions of treated firms (2)

	Full sample					
Definition of treated	Original study	Less than 5% of free emissions	Less than 10% of free emissions	Less than 15% of free emissions	Less than 25% of free emissions	Less than 50% of free emissions
	(1)	(2)	(3)	(4)	(5)	(6)
1(Auctioning)	-0.144***					
	(0.045)					
	[0.001]					
1(5pct free allowances)		0.133***				
		(0.049)				
		[0.007]				
1(10pct free allowances)			0.125***			
			(0.044)			
			[0.005]			
1(15pct free allowances)				0.142***		
				(0.042)		
				[<0.001]		
1(25pct free allowances)					0.179***	
					(0.039)	
					[<0.001]	
1(50pct free allowances)						0.261***
						(0.040)
						[<0.001]
ln(Renewable energy)	-0.136*	-0.060	-0.050	-0.048	-0.040	-0.036
	(0.075)	(0.071)	(0.070)	(0.070)	(0.069)	(0.068)
	[0.070]	[0.399]	[0.474]	[0.498]	[0.562]	[0.596]
ln(Electricity consumption)	0.988**	1.716***	1.700***	1.700***	1.730***	1.509***
	(0.425)	(0.452)	(0.450)	(0.446)	(0.442)	(0.424)
	[0.021]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
ln(GDP)	-0.965***	-0.798***	-0.812***	-0.789***	-0.752***	-0.664**
	(0.320)	(0.296)	(0.294)	(0.294)	(0.284)	(0.275)
	[0.003]	[0.007]	[0.006]	[0.008]	[0.008]	[0.016]
Net electricity exports	0.004***	0.003**	0.002**	0.002**	0.002*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
	[0.003]	[0.018]	[0.027]	[0.027]	[0.062]	[0.261]
Observations	3465	3465	3465	3465	3465	3465
Nb. of firms	385	385	385	385	385	385

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms defined as in the original study (column 1) and according to alternative treatment definitions based on the share of firms' emissions covered by free allowances (columns 2 to 6). Year and firm fixed effects. Analysis conducted on the full sample. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 6: Replication of Table 3 using alternative definitions of treated firms (3)

	Matched samples					
Definition of treated	Original study	Less than 5% of free emissions	Less than 10% of free emissions	Less than 15% of free emissions	Less than 25% of free emissions	Less than 50% of free emissions
	(1)	(2)	(3)	(4)	(5)	(6)
1(Auctioning)	-0.056					
	(0.066)					
	[0.396]					
1(5pct free allowances)		0.076				
		(0.066)				
		[0.249]				
1(10pct free allowances)			0.055			
			(0.057)			
			[0.334]			
1(15pct free allowances)				0.088*		
				(0.052)		
				[0.093]		
1(25pct free allowances)					0.118**	
					(0.054)	
					[0.030]	
1(50pct free allowances)						0.195***
						(0.055)
						[<0.001]
ln(Renewable energy)	0.124	0.000	-0.003	0.008	0.069	0.224**
	(0.125)	(0.114)	(0.108)	(0.102)	(0.109)	(0.098)
	[0.320]	[0.998]	[0.980]	[0.941]	[0.527]	[0.022]
ln(Electricity consumption)	1.390**	1.481**	1.369**	1.446**	1.369**	1.638***
	(0.541)	(0.617)	(0.632)	(0.589)	(0.536)	(0.529)
	[0.011]	[0.018]	[0.032]	[0.015]	[0.011]	[0.002]
ln(GDP)	-1.043***	-0.709**	-0.594**	-0.433	-0.380	-0.788**
	(0.324)	(0.306)	(0.297)	(0.303)	(0.368)	(0.357)
	[0.001]	[0.022]	[0.047]	[0.155]	[0.303]	[0.028]
Net electricity exports	0.002	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
	[0.137]	[0.875]	[0.971]	[0.973]	[0.976]	[0.712]
Observations	3168	1368	1611	1746	1971	2727
Nb. of firms	352	152	179	194	219	303

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms defined as in the original study (column 1) and according to alternative treatment definitions based on the share of firms' emissions covered by free allowances (columns 2 to 6). Year and firm fixed effects. Analysis conducted on matched samples. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 7: Replication of Table 3 using alternative definitions of treated firms (4)

	Full sample			Matched samples		
Definition of treated	Original study	Reduction above 75th percentile	Reduction above median	Original study	Reduction above 75th percentile	Reduction above median
	(1)	(2)	(3)	(4)	(5)	(6)
1(Auctioning)	-0.144***			-0.056		
	(0.045)			(0.066)		
	[0.001]			[0.396]		
1(Reduction above Q3)		0.115**			0.035	
		(0.051)			(0.061)	
		[0.024]			[0.568]	
1(Reduction above median)			0.206***			0.159***
			(0.038)			(0.046)
			[<0.001]			[<0.001]
ln(Renewable energy)	-0.136*	-0.083	-0.059	0.124	-0.087	0.054
	(0.075)	(0.072)	(0.070)	(0.125)	(0.098)	(0.086)
	[0.070]	[0.247]	[0.404]	[0.320]	[0.377]	[0.527]
ln(Electricity consumption)	0.988**	1.575***	1.638***	1.390**	1.308**	1.615***
	(0.425)	(0.454)	(0.440)	(0.541)	(0.634)	(0.511)
	[0.021]	[<0.001]	[<0.001]	[0.011]	[0.041]	[0.002]
ln(GDP)	-0.965***	-0.719**	-0.665**	-1.043***	-0.607**	-0.475
	(0.320)	(0.300)	(0.281)	(0.324)	(0.303)	(0.307)
	[0.003]	[0.017]	[0.019]	[0.001]	[0.047]	[0.124]
Net electricity exports	0.004***	0.003**	0.001	0.002	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
	[0.003]	[0.011]	[0.178]	[0.137]	[0.982]	[0.984]
Observations	3465	3402	3402	3168	1368	2466
Nb. of firms	385	378	378	352	152	274

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms defined as in the original study (columns 1 and 4) and according to alternative treatment definitions based on the reduction rate of firms' emissions being covered by free allowances (columns 2,3,5 and 6). Year and firm fixed effects. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 8: Replication of Table 4 using alternative definition of small firms (Small emitters sample)

Percentile used as threshold		10 (1)	15 (2)	20 (3)	23 (4)	**Original study** **25** **(5)**	27 (6)	30 (7)	35 (8)	40 (9)
Treated*After			-0.147**	-0.111	-0.162	**-0.192***	-0.176*	-0.130	-0.100	-0.097
	Do not run, not enough observations		(0.070)	(0.124)	(0.102)	**(0.097)**	(0.095)	(0.112)	(0.134)	(0.130)
			[0.044]	[0.379]	[0.117]	**[0.052]**	[0.070]	[0.249]	[0.456]	[0.456]
Nb. of firms			29	45	55	**62**	69	78	95	114
Nb. of obs.			486	756	918	**1044**	1152	1314	1584	1854

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms, in 2013. Specification and controls as in the original study Table 4, Column 2. Standard errors associated with reported Treated*After estimated coefficients in parenthesis, p-values in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 9: Replication of Table 4 using alternative definition of small firms (Large emitters sample)

Percentile used as threshold		10 (1)	15 (2)	20 (3)	23 (4)	**Original study** **25** **(5)**	27 (6)	30 (7)	35 (8)	40 (9)
Treated*After			-0.056	-0.046	-0.044	**-0.042**	-0.043	-0.063	-0.073	-0.064
	Results no, reported observations		(0.040)	(0.042)	(0.044)	**(0.043)**	(0.044)	(0.044)	(0.047)	(0.048)
			[0.163]	[0.276]	[0.314]	**[0.325]**	[0.329]	[0.160]	[0.129]	[0.138]
Nb. of firms			229	215	205	**203**	199	178	159	158
Nb. of obs.			3096	2916	2772	**2772**	2700	2376	2124	2124

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms, in 2013. Specification and controls as in the original study Table 4, Column 5. Standard errors associated with reported Treated*After estimated coefficients in parenthesis, p-values in brackets. Significant at the ***[1%] **[5%] *[10%] level.

Table 10: Replication of Table 4 using alternative emissions threshold (Small emitters sample)

Variable used to define the threshold	**Original study 2009 emissions, two thresholds (1)**	2009-2012 emissions, two thresholds (2)	2009 emissions, one threshold (3)	2009-2012 emissions, one threshold (4)
Treated*After	**-0.192***	-0.185*	0.104	0.104
	(0.097)	(0.098)	(0.148)	(0.148)
	[0.052]	[0.064]	[0.486]	[0.486]
Nb. of firms	**62**	62	59	59
Nb. of obs.	**1044**	1044	990	990

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms, in 2013. Specification and controls as in the original study Table 4, Column 2. Standard errors associated with reported Treated*After estimated coefficients in parenthesis, p-values in brackets. Significant at the ***[1%] **[5%] *[10%] level. All threshold are computed at the 25^{th} percentile of the distribution. "Two thresholds" means we computed one threshold using data on emissions of the treated firms for the treated group, and one threshold using data on emissions of the control firms for the control group, as in the original study. "One threshold" means we computed a unique threshold using the entire distribution of emissions data. "2009 emissions" means we used emissions in 2009 as in the original study. "2009-2012" emissions means we used the average emissions from 2009-2012 for each firm to compute the threshold (the variable used for matching in the original study).

Table 11: Replication of Table 4 using alternative emissions threshold (Large emitters sample)

Variable used to define the threshold	**Original study 2009 emissions, two thresholds (1)**	2009-2012 emissions, two thresholds (2)	2009 emissions, one threshold (3)	2009-2012 emissions, one threshold (4)
Treated*After	**-0.042**	-0.044	-0.077	-0.072
	(0.043)	(0.045)	(0.052)	(0.053)
	[0.325]	[0.331]	[0.138]	[0.177]
Nb. of firms	**203**	199	272	273
Nb. of obs.	**2772**	2682	3744	3762

Notes: OLS regressions of the natural log of firm-level emissions on a policy dummy switching from zero to one after the start of the treatment period for treated firms, in 2013. Specification and controls as in the original study Table 4, Column 5. Standard errors associated with reported Treated*After estimated coefficients in parenthesis, p-values in brackets. Significant at the ***[1%] **[5%] *[10%] level. All threshold are computed at the 25^{th} percentile of the distribution. "Two thresholds" means we computed one threshold using data on emissions of the treated firms for the treated group, and one threshold using data on emissions of the control firms for the control group, as in the original study. "One threshold" means we computed a unique threshold using the entire distribution of emissions data. "2009 emissions" means we used emissions in 2009 as in the original study. "2009-2012" emissions means we used the average emissions from 2009-2012 for each firm to compute the threshold (the variable used for matching in the original study).

Table 12: Test of heterogeneity of effects by firm size

FE regression	Full sample (1)	Full sample (2)	Matched sample (3)	Matched sample (4)
1.Auctioning#1.post_treat	-0.196**	-0.214**	-0.124	-0.106
	(0.097)	(0.099)	(0.118)	(0.117)
	[0.045]	[0.030]	[0.293]	[0.364]
1.Auctioning#1.post_treat#1.large	0.134	0.108	0.037	0.032
	(0.106)	(0.106)	(0.124)	(0.119)
	[0.207]	[0.310]	[0.764]	[0.790]
ln(RE)		-0.125*		0.125
		(0.073)		(0.120)
		[0.089]		[0.298]
ln(elec cons)		0.881**		1.269**
		(0.418)		(0.565)
		[0.036]		[0.025]
Net elec exp		0.003**		0.002
		(0.001)		(0.001)
		[0.019]		[0.245]
ln(GDP)		-0.850***		-0.990***
		(0.309)		(0.329)
		[0.006]		[0.003]
cons	12.520***	14.652***	12.486***	9.319
	(0.016)	(4.610)	(0.032)	(5.924)
	[0.000]	[0.002]	[0.000]	[0.117]
Observations	3,465	3,465	5,112	5,112
Nb of firms	385	385	352	352

Notes: This table provides the results of an alternative specification for the FE model regressions that includes a dummy that takes the value of one for large firms, in interaction with the treatment. Robust standard errors are in parentheses, clustered by firm. P-values are reported in brackets. Significant at the ***[1%] **[5%] *[10%] level.