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Free Allocation and the Endowment Effect in Cap-and-Trade Systems: Evidence from the European Electricity Sector

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Free Allocation and the Endowment Effect in Cap-and-Trade Systems: Evidence from the European Electricity Sector

February 29, 2016

Independence of installation-level emissions from endowments of allowances allocated for free constitutes a necessary condition for the cost-effectiveness of a cap-and-trade system. A causal relationship between allocations and emissions suggests the presence of an endowment effect induced by free allocation and indicates a loss in cost effectiveness. The issue is relevant to the EU's Emissions Trading System (EU ETS), where a large share of the total allocation occurs for free. This paper tests for the presence of an endowment effect among European electricity sector plants as regulated under the EU ETS by evaluating whether growth in plant-level emissions of power generators changed due to a switch from free allocation to full auctioning. To overcome the endogeneity of allocations I exploit a natural experiment inducing exogenous variation in the allocation of allowances to power producers. While electricity producers located in EU-15 countries were subject to full auctioning starting in 2013, free allocation continued under the so-called 10c rule in eight member states. I apply a matched difference-in-differences research design to a unique EU-wide plant-level dataset of emissions and technical characteristics, constructing a synthetic control group. I find no evidence of a general endowment effect. However, there is some evidence in favor of an endowment effect for a sub-sample of small emitters.

JEL codes: Q54, Q58, Q52, C22, C23

Keywords: EU ETS, emissions, free allocation, endowment effect,
policy evaluation, treatment effects

1 Introduction

Potentially distorting effects of free allocation on the workings of cap-and-trade systems are of enduring interest in the research and policy communities, as an absence of distortionary effects of free allocation may be viewed as a necessary condition for the cost-effectiveness of a cap-and-trade scheme. Whether such distortions occur is of particular interest for cap-and-trade regimes in which a large portion of the overall allowance allocation occurs through annual endowment streams for the affected installations free of charge. In idealized settings allocations and emissions are independent, so that any arbitrary distribution of property rights will not affect trading and emission outcomes (Coase, 1960). It would be advantageous if this independence property would hold in operational cap-and-trade systems, as it gives policy makers the ability to use free allocation politically without the cap-and-trade system suffering negative consequences in terms of cost effectiveness (Hahn and Stavins, 2011). However, in a real-world cap-and-trade system endowments of free allocation may distort emission outcomes, e. g. in the presence of transactions costs (Coase, 1960; Stavins, 1995) or behavioral anomalies causing firms to not fully internalize the opportunity cost of free allocation (Kahneman, Knetsch and Thaler, 1991). Evaluating if free allocation causally affects emissions is therefore of major relevance. This paper addresses the research question of whether free allocation in the EU ETS causally affects plant-level emissions in the European electricity sector. Analyzing this question in the context of the electricity sector is relevant, as power generation has been the main focus of European climate policy to date and is generally regarded as the most sophisticated sector regulated under the EU ETS.

The insight that in the absence of significant frictions optimal emissions at the unit level are invariant to the initial allocation of property rights goes back to Coase (1960). This invariance has been termed the independence property in cap-and-trade systems (Hahn and Stavins, 2011). It has been shown to hold in a frictionless cap-and-trade system, as long as allocation occurs in a lump-sum fashion, by Montgomery (1972). However, there are a number of reasons why the independence property may fail in a real-world cap-and-trade system with installations receiving endowments of allowances free of charge, even if allocation is lump-sum. Transaction costs (Stavins, 1995) or imperfect competition (Hahn, 1984) may distort installation-level emissions outcomes. Independence may also fail due to behavioral anomalies. The behavioral literature finds that in experimental settings

subjects value endowments of goods differently depending on whether they receive them for free or have to trade for them, leading to under-trading in the market (Kahneman, Knetsch and Thaler, 1990). Some experimental evidence of such behavior exists for settings designed to mimic emissions trading systems (Murphy and Stranlund, 2007). Such behavior leads to a loss in cost-effectiveness in a cap-and-trade system.

However, it is challenging to evaluate whether a causal relationship exists between installation-level allocations and emissions using empirical analysis. This difficulty is due to the endogeneity of allocations, which are typically set based on (unobserved) historical plant-level emissions. Therefore, an exogenous source of variation in allocations is required to identify their causal effect on emissions. For this reason the empirical literature on the causal relationship between allocation and emissions in cap-and-trade systems is sparse, to the best of my knowledge consisting of two papers: Fowlie and Perloff (2013) consider this question in the context of California’s RECLAIM program by relying on an instrumental variable approach to identification. Reguant and Ellerman (2008) ask the same question for Spanish thermal power plants regulated under the EU ETS during ETS Phase I (2005-2007), exploiting the variation induced by a non-linearity in the national allocation rule for identification. Both papers do not find a significant endowment effect. This paper contributes to this literature by evaluating whether an endowment effect exists in the European electricity sector, the most highly emitting sector regulated under the EU ETS. More broadly, by pursuing a micro-level approach to ex post evaluation this study also contributes to a growing empirical literature analyzing European climate policy at the micro level (Martin et al., 2014; Petrick and Wagner, 2014; Calel and Dechezlepretre, 2015), as well as to the wider literature evaluating the effects of environmental policy on firm behavior, e.g. Levinson (1996); Greenstone (2002).

The analysis in this paper benefits from a natural experiment providing a large and broadly based source of exogenous variation in installation-level allocations due to a natural experiment. The power sector regulated under the EU ETS has been subject to a synchronized move from free allocation to full auctioning for power-generating installations between the last year of Trading Phase II, 2012, and the first year of Phase III, 2013.¹ However, only installations in the EU-15 member states were subject to this change in the allocation regime, as a temporary derogation has preserved free allocation for installations in eight EU member states until at least 2020 under the so-called 10c rule (OJEU,

¹EU-15 power producers still receive free allowances for heating services provided by power plants.

2009).² I exploit this exogenous change in allocation rules affecting only a subset of power plants, while other relevant features remained constant. This identifies the causal effect of discontinuing free allocation in favor of full auctioning on plant-level emissions.

I apply a matched difference-in-differences (diff-in-diff) research design to a panel of plant-level data covering the European power generation sector for the period 2008-2014, i.e. the dataset contains five pre-treatment observations and two post-treatment observations for each plant. The dataset used in the analysis is a unique match of installation-level emissions data from the EU Transaction Log (EUTL) and a Platts power plant database providing plant-level technical information such as capacity, fuel technology and whether an installation is a combined heat and power (CHP) plant. The matched diff-in-diff research design combines the advantages of diff-in-diff analysis with matching-on-observables approaches, while the panel structure of the data allows for an inclusion of plant-level fixed effects and trends. I conduct the analysis for the full sample of installations, as well as for the sub-sample of small installations with a capacity of up to 50 MW.

The results for the full sample fail to find a significant endowment effect, which is in line with the results by Fowlie and Perloff (2013) and Reguant and Ellerman (2008). However, the analysis of the small plants sub-sample provides some evidence of a temporary effect, during the first post-treatment period, of switching to full auctioning on emissions. The (negative) growth in plant-level emissions is estimated to accelerate temporarily due to the advent of full auctioning, suggesting a level effect of switching to full auctioning for small plants. These results suggest that the level of emissions may have been higher than optimal with free allocation in place and has been adjusted downward through a temporary acceleration of the plants' de-carbonization rate during the first post-treatment period. Once the adjustment was made emissions growth was no longer significantly different for plants subject to free allocation and full auctioning, respectively. While the effect is no longer significant when employing the most demanding specification, which includes plant-level trends, this result suggests the presence of a distortion in the behavior of small plants on account of free allocation, leading to higher than optimal emissions under free allocation. Based on the analysis so far I conclude that caution regarding the liberal application of free allocation may be warranted.

The remainder of the paper is structured as follows: Section 2 introduces the empiri-

²The countries are Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland, and Romania. The current policy debate suggests that free allocation for these countries may continue until at least 2030 (EU-COM, 2015).

cal strategy, while Section 3 outlines the administrative background to the identification strategy. Section 4 presents the research design, section 5 describes the datasets and gives a descriptive overview, whereas in Section 6 I present estimation results. Section 7 summarizes and concludes.

2 Empirical Strategy

2.1 Endogeneity of Allocations

A naive regression of plant-level emissions on plant-level allocation would produce spurious results. The reason is that in the EU ETS the allocation for each plant is determined based on historical emissions, which are unobservable to the analyst. Allocations are determined for the entire duration of a Trading Phase, and are either constant or decrease at some deterministic rate during the Phase. For each new Trading Phase in the EU ETS allocations are computed based on average emissions of some pre-specified base period. Phase II allocations were determined using data from Phase I, while Phase III allocations are based on Phase II information. However, the plants' technology cannot be changed easily without a major reconstruction of the plant, giving rise to strong auto-correlation of plant-level emissions. Thus, even allocations in later Phases are still strongly related to the installations' historical emissions prior to the start of the EU ETS. For these reasons a regression of current emissions on current allocations would yield inconsistent estimates due to the endogeneity of allocations. Therefore, any naive regression of current emissions on current allocation will only produce a correlation. A causal analysis requires a source of exogenous variation in the allocation variable, i.e. not related to the plant's past emissions.

2.2 Exploiting a Natural Experiment for Identification

To identify the causal effect of allocations on emissions, I exploit exogenous variation in the allocation variable induced by a natural experiment, which occurred in 2013. While free allocation expired in favor of full auctioning for electricity producers in the EU-15 countries between the end of EU ETS Phase II in the 2012 compliance year and the start of Phase III with the 2013 compliance year, free allocation continues in eight of the EU's new member states until at least 2020 under the so-called 10c rule. Therefore, EU-15 installations constitute the treatment group, while the plants subject to the 10c rule are the control group. The treatment occurs simultaneously for all treated plants, allowing for

a straightforward descriptive analysis and a clear specification in the regression analysis. A further advantage from the point of view of the analysis in this paper is that the change in rules occurred sharply, with no transition period. This allows for a straightforward distinction regarding treatment status of the affected plants, as well as a clear definition of the pre-treatment and post-treatment periods. Section 3 provides details on the rules used to distinguish the sample of plants in treatment and control groups.

3 Background

3.1 Full Auctioning of Allowances for Power Producers

The EU Directive 2009/29/EC (OJEU, 2009) provides the legal framework for the EU ETS during Phase III, which covers the period 2013-2020. Article 10 posits that starting in Phase III, i.e. with the 2013 compliance year, power producing installations shall be subject to full auctioning of emissions allowances. Cogeneration units may continue to receive some free allocation, but only for the generation of heating and cooling. District heating plants also continue receiving free allocation for the emissions involved in generating heat. This means that the electricity sector transitioned rapidly from widespread free allocation to full auctioning to essentially full auctioning between the 2012 and 2013 compliance years.

Figure 1 shows the change in plant-level allocations from 2012 (vertical axis) to 2013 (horizontal axis). An identical allocation in both years would have placed observations on the 45 degree axis. A switch from 100% free allocation to full auctioning would order all observations along the vertical axis. The small departures from the vertical axis demonstrate the residual free allocation remaining at the start of the 2013 compliance year.

3.2 Continued Free Allocation under the 10c Rule

Article 10c lays out the rules for continued free allocation to installations generating electricity during Phase III. Member states governments may apply for an extension of free allocation if (a) their national electricity network was either not or only poorly connected to the interconnected European electrical grid operated by the Union for the Coordination of Transmission of Electricity (UCTE) in 2007 or (b) if more than 30% of the country's electricity was generated from a single fossil fuel and GDP per capita was at most 50% of

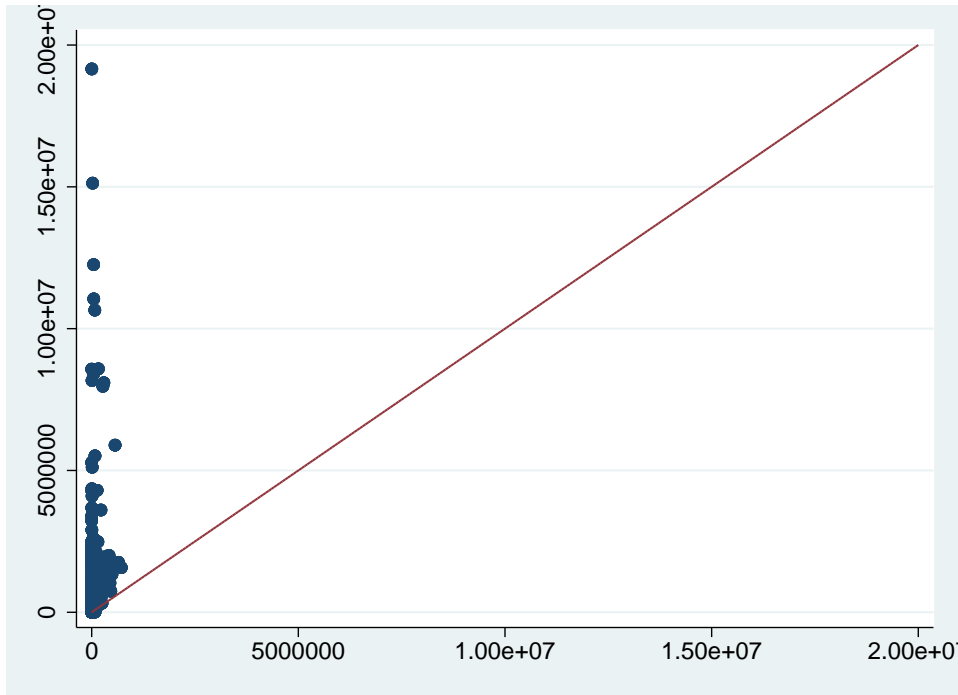


Figure 1: Installation-Level Allocations in 2012 and 2013

Source: EUTL.

the EU level in 2006. Power plants either in existence or *physically initiated* by December 31, 2008 were eligible to receive allowances for free.³ Communication 2011/C 99/03 (OJEU, 2011) provides details on the implementation of Article 10c. The stated goal of continued free allocation under is to support installations in the affected states with modernization measures and to avoid undue increases in electricity prices, which may occur with a shift to full auctioning. Allowances allocated for free under the 10c rule were subtracted from each member states auctioning contingent, i.e. member states opting for free allocation under the 10c rule incurred the consequence of decreased revenue from auctioning allowances.

Installations in ten EU members states are eligible to receive free allocation under the 10c rule, all of them countries who joined the EU after 2004. The countries eligible are Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland and Romania. Out of the member states eligible for continued free allocation only Latvia and Malta declined to use this option. Each member state using the provision under the 10c rule had to submit a list of possible investment options in modernizing its power

³The condition of being physically initiated is not entirely clear, but does not imply mean that the plant was under construction by December 31, 2008. Therefore, plants that would come online years later would also be eligible for free allocation.

sector for approval by the European Commission by September 30, 2011. The total value of investments had to be at least equal to the market value of freely allocated allowances at that time. Member states have to report to the Commission on the progress of investments each year. The lists of investment options submitted by the affected member states and approved by the Commission exceeded the value of free allocation, so that installations' operators had several options to conduct their modernization measures and were therefore not tied to specific measures.

For purpose of this study it is of interest whether free allocation under the 10c rule should make us expect different emissions pattern among the group of installations continuing to receive free allocation under this rule after the start of Phase III, compared to the pattern previously. It is difficult to draw conclusions, as there is little transparency in this process. However, evidence based on the grey literature suggests that investment projects under 10c rule did not necessarily lead to systematic decrease in emissions of the affected installations. The proposed lists of investments have been criticized to contain further investment in fossil fuel generation facilities by incumbent companies, and that a large portion of projects intended to modernize not generation of electricity production of heat (Popa and Ceperaga, 2012). This suggests that the investments under 10c did not systematically decrease emissions of the affected installations. We therefore conclude that free allocation under the 10c rule was a political concession to governments in new EU member states, giving them the ability to continue subsidizing electricity producers in exchange for lower auction revenues. Therefore there is no reason to believe that behavior of power producers under the 10c rule should be significantly different, as far as the effect of free allocation on emissions is concerned, from what it was during Phase II.

4 Research Design

4.1 Outcome Variable

The outcome variable is specified as a normalized growth rate in emissions, analogous to Davis and Haltiwanger (1992) and Greenstone (2002):

$$y_{it} = \frac{e_{it} - e_{it-1}}{\frac{e_{it} + e_{it-1}}{2}}$$

Specifying the outcome variable in this manner has several advantages. It allows us

to track changes in emissions over time while also capturing the entry and exit of plants. Values of y_{it} are contained in the the $[-2,2]$ interval, with a value of 2 indicating plant entries and -2 capturing plant closures. Moreover, using a growth rate in our regression analysis helps reduce the influence of outliers with very large emissions, which may drive results if the regressions are conducted in levels.

4.2 Econometric Model

In our diff-in-diff analysis we run the following regression, both on an unmatched and a matched sample.

$$y_{it} = \alpha_i + \alpha_i * t + \lambda_t + \rho d_{it} + \epsilon_{it}$$

where y_{it} is the normalized growth rate of emissions of plant i in year t , ρ is the average treatment effect on the treated (ATT) of the change from free allocation to auctioning on emissions. α_i is a plant-level fixed effect, $\alpha_i * t$ a plant-specific time trend, λ_t a time fixed effect. Standard errors are clustered at the plant level to robustify against serial correlation in ϵ_{it} . As we have two post-treatment periods available, we estimate the ATT for each year, allowing us to evaluate the dynamic response to the treatment.

We control for a range of unobserved heterogeneity by including a fixed effects and trends. The preferred version of the model controls for installation-level fixed effects, time fixed effects and installation-level trends. Including time fixed effects controls for shocks affecting all installations symmetrically, e.g. changes in fuel prices that are largely determined globally. Installation-level fixed effects capture unobserved factors affecting an installation in a constant way over time and nest fixed effects at regional or country level, e.g. country-level renewable energy support schemes or energy efficiency policies or plant-level production technology. Installation-level time trends control for differential trajectories installations may experience with respect to emissions over time, e.g. plant-level changes in productivity. Including the latter is demanding in terms of specification, as a lot of installation-level variation in y_{it} is captured by the installation-level trends.

4.3 Matching: Synthetic Control Group

As usual in causal analysis, constructing the unobserved counterfactual is one of the main challenges. Given the differences in the configuration of power systems within countries,

but also between the treatment and control groups, we construct a matched sample with a synthetic control group that is similar to the treatment group according to important observables (e.g. Abadie and Gardeazabal (2003)). The idea behind synthetic control is analogous to other matching methods, e.g. propensity score matching, where matched samples are constructed by choosing observations from the control group such that the control group is very similar to the treatment group based on certain co-variables.

I follow the entropy balancing approach suggested by Hainmueller (2012) and applied by e.g. Marcus and Siedler (2015) to generate the matched sample. The expected value of the outcome for the treated group in the counterfactual absence of treatment, $E[Y(0)|D = 1]$, is estimated by re-weighting observations in the control group:

$$E[\widehat{Y(0)}|D = 1] = \frac{\sum_{i|D=0} Y_i w_i}{\sum_{i|D=0} w_i}$$

The weights are chosen to minimize the entropy distance metric

$$\min_{w_i} H(w) = \sum_{i|D=0} w_i \log(w_i/q_i),$$

where q_i are uniformly distributed base weights. The minimization occurs such that pre-treatment moments of variables specified by the researcher are exactly equalized across treatment and control groups. We simultaneously match on pre-treatment emissions, the share of major fuel type, the share of combined heat and power plants and capacity in MW. Table 1 shows the divergence of these variables before and after the matching. Unlike in propensity score matching balancing tests are not required, since exact balance between the groups is part of the constraint imposed on the matching algorithm.

5 Data and Descriptive Statistics

5.1 Data

Installation-level data on CO₂ emissions by electricity generating installations belonging to firms whose main share of emissions stems from electricity generation are drawn from the European Union Transaction Log (EUTL). I consider installations that report emissions for every year of the sample period, i.e. "stayers" according to Greenstone (2002). I

Table 1: Comparison of Means in Treatment and Control Groups, Pre- and Post Matching

	Treatment	Control	
		Non-Matched	Matched
Emissions Growth 2009	-0.090	-0.146	-0.090
Emissions Growth 2010	-0.047	0.009	-0.047
Emissions Growth 2011	-0.218	0.002	-0.218
Emissions Growth 2012	-0.161	-0.239	-0.161
Coal	14.8%	61.4%	14.8%
Gas	50.7%	23.8%	50.7%
Oil	22.9%	6.4%	22.9%
Combined Heat and Power	42.5%	53.2%	42.5%
Capacity (MW)	395.4	460.3	395.4
No. installations	701	109	

exclude new entrants and plant closures.⁴ The sample period in this paper is 2008-2014, i.e. the sample begins with the start of Phase II, when the EU ETS took its current open-ended shape. This provides a panel of 738 treated and 103 control installations covering five pre-treatment and two post-treatment periods. The EUTL data were matched with a version of the Platts Power Plant Database.

An important part of the data work was to identify electricity producing installations belonging to firms whose majority of emissions came from the production of electricity, to achieve a sharp focus on the electricity sector.⁵ The mapping of installations to sectors and the decision whether an installation should be included in the sample was based on the information in the Ownership Links and Enhanced EUTL Dataset Project and proceeded in two steps.⁶ First, all installations with the NACE code 35.11 ("production of electricity") were flagged. Then I compared NACE codes at the installation and firm levels. If a firm only consisted of 35.11 category installations all of them were kept. The second step involved installations with a NACE code of 35.11 that belonged to firms whose emissions also came from other activities, i.e. 35.11 installations belonging to firms who also had at least one installation with a NACE code other than 35.11. I went through these cases one by one according to the following decision rule: If the majority of a firm's emissions were generated by 35.11 coded installations, i.e. a firm whose main activity is

⁴The paper will also consider information on entering and exiting installations in its next iteration.

⁵A significant number of installations classified as power producing belongs to firms whose primary activity is industrial production.

⁶Jaraite, J., T. Jong, A. Kazukauskas, A. Zaklan, and A. Zeitlberger. Ownership Links and Enhanced EUTL Dataset. European University Institute, Florence, 2013. Available online at <http://fsr.eui.eu/CPRU/EUTLTransactionData.aspx>

the production of power, then all of the 35.11 installations were kept in the sample. If the majority of emissions came from other activities, then all the 35.11 installations from that firm were removed from the sample. In several cases this involved deciding whether a firm was mainly active in power or heat generation according to the European Commission data. Another example of multiple NACE codes at the firm level are industrial firms, e.g. producers of steel, whose CO₂ emissions are a mixture of process emissions and emissions from electricity generated by their own power plants.

About two thirds of the EUTL Data were matched to a version of the Platts Power Plant Database designed for compatibility to EU ETS data on CO₂. The remaining installations were matched using a manual case-by-case online search. This matching provides information on plant-specific technical characteristics not available in the EUTL, such as the primary fuel type, whether a plant is a combined heat and power plant (CHP), generation capacity, and emission intensity.

5.2 Descriptive Analysis

Table 2 provides descriptive statistics on treated and control installations, respectively, showing that the basic configuration of the plant fleets differs quite strongly between the treatment and control groups. We observe that the mean treated installation produces about half the emissions of the average control installation, while having an average capacity some 20% lower than the average control group plant. This indicates that plants in the control group are significantly more emission intensive. The treatment group also has a much higher share of small plants and a lower share of medium-sized plants. The share of large plants is similar in both groups. In terms of fuel type, the fleet of power plants in the treatment group features a much larger number of gas-fired plants, as opposed to the predominance of coal-fired plants in the control group. Finally, a higher portion of control group plants are CHP plants, suggesting higher share of must-run plants with less operational flexibility in the control group due to contractual obligations to provide heating.

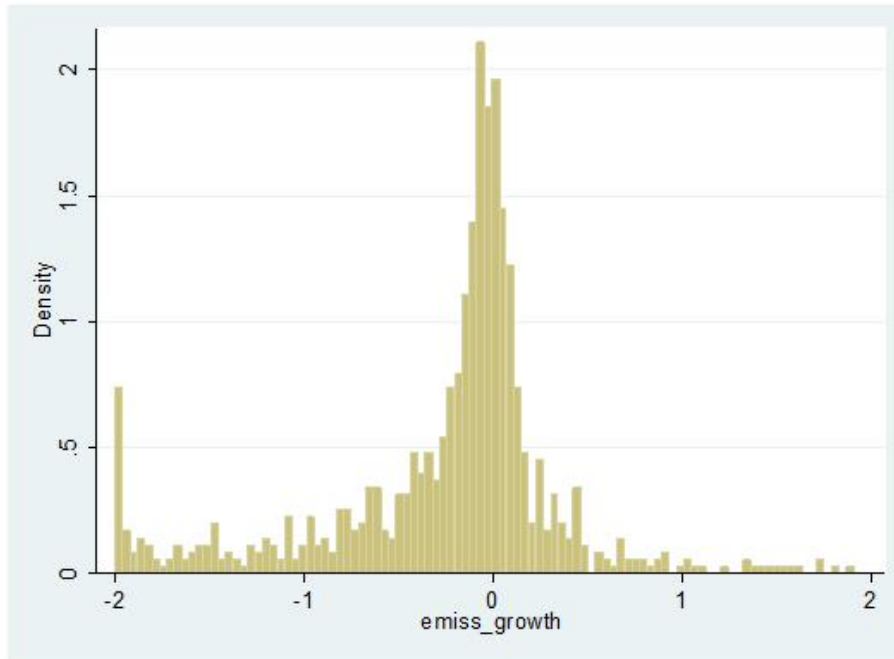
Figure 2 illustrates the distribution of growth rates in emissions over all installations for the period 2012-2013, i.e. the period immediately after the treatment. We observe that growth rates are centered around zero, i.e. many installations had unchanged emissions between the two years. However, there is more mass on the left-hand side of the distribution than on the right, i.e. more installations decreased emissions after the treatment.

Table 2: Descriptive Statistics by Treatment Status

	Treatment		Control	
	Obs.	Mean	Obs.	Mean
Verified Emissions (1,000 mt)	4959	878	679	1,757
Free Allocation (1,000 mt)	4284	585	671	1,475
Capacity (MW)	4842	388	672	466
Small plants (<50MW), share in %	4842	34.3%	672	21.4%
Medium plants (51-200MW), share in %	4842	20.2%	672	37.5%
Large plants (>201MW), share in %	4842	45.5%	672	41.1%
Gas-fired, share in %	4842	50.4%	672	24.1%
Coal-fired, share in %	4842	14.6%	672	59.8%
Oil-fired, share in %	4842	23.1%	672	6.3%
Combined heat and power, share in %	4848	42.2%	660	52.7%

Moreover, a significant number of plants reported zero emissions in 2013, about 0.7% of the installations in the sample, meaning that a significant number of plants exited the EU ETS in 2013.

Figure 2: Normalized Growth Rate in Installation-Level Emissions, 2012-2013

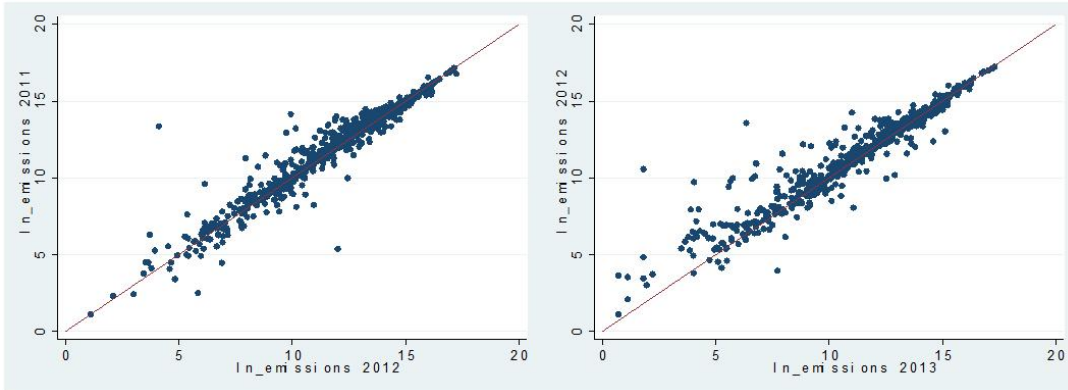


Source: EUTL and own calculations.

Figure 3 show the natural log of installation-level emissions during the last two pre-treatment years (left-hand panel) and the last pre-treatment vs. the first post-treatment period (right-hand panel). An installation with no change in emissions lies on the 45 degree line, installations with a drop in emissions are above and those with an increase below. We

note that for high levels of emissions installations lie very close to the 45 degree line before and after the treatment, i.e. the level of emissions for these installations is similar before and after the the treatment. However, a number of plants with lower levels of emissions exhibit a decrease in emissions after the treatment, suggesting that smaller plants may be responding to the treatment more strongly than larger ones.

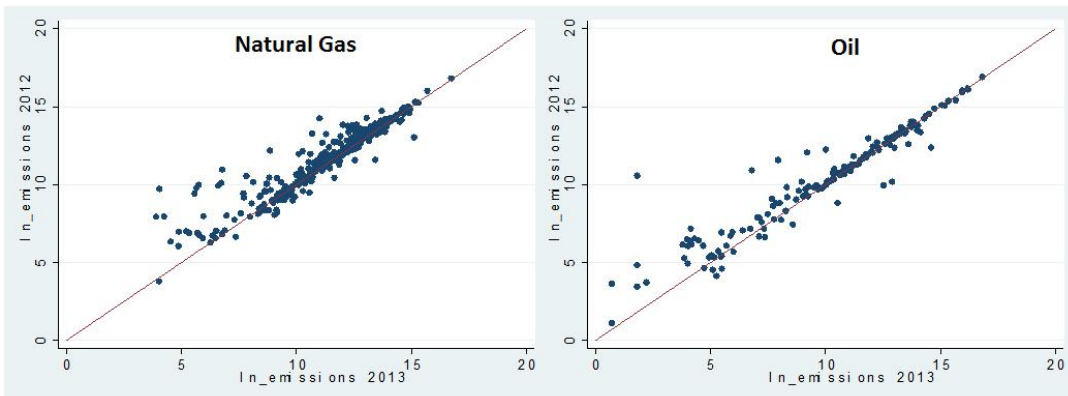
Figure 3: CO₂ Emissions of Treated Installations before and after Treatment



Source: EUTL, and own calculations.

This change in emissions appears to be concentrated among natural gas and oil fired plants (Figure 4), with coal fired plants affected less. Installations in the control group remain close to the 45 degree line during the same period of time.

Figure 4: CO₂ Emissions of Treated Installations before and after Treatment, by Fuel Type



Source: EUTL, Platts, and own calculations.

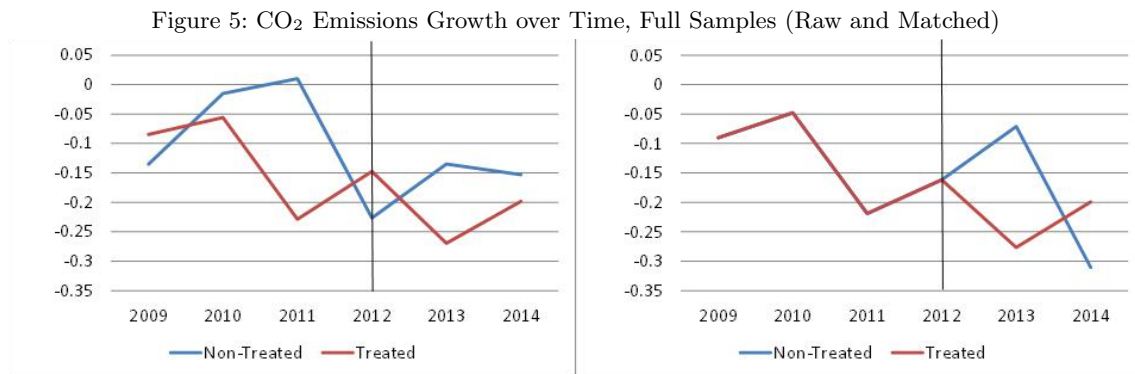
Thus, the descriptive analysis suggests that the treatment effect may be concentrated among a sub-sample of smaller plants. The regression analysis will therefore devote attention to estimating treatment effects for both the full sample and the sample of small

power plants with a capacity of up to 50 MW.⁷

6 Results

6.1 Parallel Trends

This section presents the development of the mean of the outcome variable over time, for the raw and matched full samples, respectively, as well as for the corresponding small plants sub-samples. The vertical line in each panel indicates the period in which treatment occurred. This allows us to evaluate the appropriateness of the parallel trend assumption identification of the diff-in-diff approach relies on. Figure 5 shows the evolution of y_{it} in the full samples, using the raw sample to form the control group (left-hand panel) and the synthetic control group (right-hand panel).

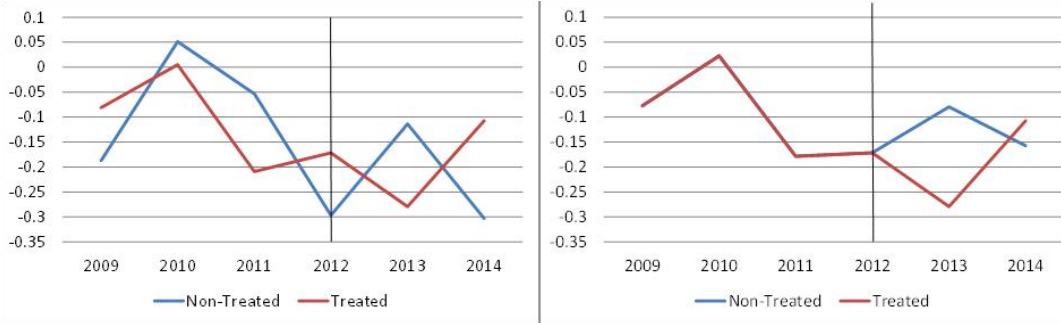


We observe that the pre-treatment trends are somewhat but not closely parallel for the unmatched full sample, providing additional motivation for controlling for plant-level trends in the regression analysis. In contrast, the matched sample exhibits identical pre-treatment outcomes by construction. Visual inspection of y_{it} in the two post-treatment periods reveals a drop in the growth rate of emissions in the treatment group compared to the control group in the first post-treatment year and a convergence of growth rates in the second post-treatment period. This temporary deviation in emissions is more pronounced in the matched sample. Figure 6 repeats the exercise for the small plants sub-sample containing plants with a capacity of up to 50 MW. The pre-treatment outcome in the unmatched sample (Figure 6, left-hand panel) is much more similar, bolstering the validity of the parallel trend assumption even in the raw sample. The matched sample again shows

⁷Designating plants with a capacity of up to 50 MW as small follows the convention adopted by electricity market experts.

a perfect match of the growth in pre-treatment emissions. The small plants sub-sample exhibits a similar post-treatment behavior of y_{it} . Again, we observe a drop in the growth rate of emissions in the treatment group, compared to the control group. In the second post-treatment period we observe another convergence in y_{it} .

Figure 6: CO₂ Emissions Growth over Time, Small Plants (< 50 MW) Sub-Samples (Raw and Matched)



Based on a visual inspection we conclude that the parallel trend assumption is plausible, especially for the small plants sub-sample. The behavior of y_{it} after the treatment suggests the potential presence of a temporary effect of changing the allocation regime from substantial free allocation to full auctioning of allowances. The regression analysis will provide statistical evidence on the significance of the observed post-treatment behavior.

6.2 Regression Analysis

The results for the full sample show a significant negative effect of switching from free allocation to full auctioning on the growth rate of CO₂ emissions in the least demanding specification, in which we control for installation-level fixed effects only. Quantitatively, the effect is similar in magnitude across the raw and matched samples. The expiration of free allocation is estimated to accelerate de-carbonization in the European electricity sector in each post-treatment year at a declining rate, by 16.7% in 2013 and 10.4% in 2014 in the matched sample.

However, the effect becomes marginally insignificant in both samples once we control for year fixed effects, in addition to installation fixed effects. Including installation-level trends, by far the most demanding specification, especially when no further time-varying installation-level covariates are available, predictably increases the goodness-of-fit of the regressions. Doing so renders the treatment effect completely insignificant, although the

coefficients are similar to the previous case. Based on these results we fail to conclude in favor an endowment effect in the European electricity sector. The evidence suggests that this type of endowment-based distortion does not affect the electricity sector regulated under the EU ETS, which is good news in terms of cost-effectiveness of the market.

Table 3: Results Full Sample

	Raw sample			Matched sample		
	(1)	(2)	(3)	(4)	(5)	(6)
ATT 2013	-0.171*** (0.00)	-0.096 (0.12)	-0.075 (0.39)	-0.167*** (0.00)	-0.223 (0.11)	-0.235 (0.29)
ATT 2014	-0.113*** (0.00)	-0.006 (0.91)	0.031 (0.74)	-0.104*** (0.00)	0.086 (0.51)	0.064 (0.78)
Installation FE	x	x	x	x	x	x
Year FE		x	x		x	x
Installation-level trends			x			x
R ²	0.21	0.22	0.41	0.20	0.23	0.41
Obs.	5,608	5,608	5,608	5,212	5,212	5,212

Note: p-values for robust s.e. clustered at installation level in parentheses.

*, **, *** indicate significance at 10%, 5% and 1% levels, respectively.

The descriptive analysis suggested that if there is an endowment effect, it may especially affect small plants. This observation motivates a separate set of regressions for the sub-sample of small power plants, with a capacity of up to 50 MW. Qualitatively the estimates confirm the results for the full sample. However, there is stronger evidence of an endowment effect in the small plants sub-sample, with the difference that the effect is estimated to be temporary. It is never significant in the second post-treatment period.

Table 4: Results Small Plants (< 50 MW) Sample, Matched

	Raw sample			Matched sample		
	(1)	(2)	(3)	(4)	(5)	(6)
ATT 2013	-0.210*** (0.00)	-0.173 (0.38)	-0.114 (0.70)	-0.210*** (0.00)	-0.196* (0.08)	-0.130 (0.49)
ATT 2014	-0.056 (0.25)	0.168 (0.35)	0.213 (0.500)	-0.056 (0.25)	0.035 (0.80)	0.088 (0.67)
Installation FE	x	x	x	x	x	x
Year FE		x	x		x	x
Installation-level trends			x			x
R ²	0.19	0.21	0.40	0.21	0.23	0.45
Obs.	1,701	1,701	1,701	1,673	1,673	1,673

Note: p-values for robust s.e. clustered at installation level in parentheses.

*, **, *** indicate significance at 10%, 5% and 1% levels, respectively.

The main difference compared to the analysis of the full sample is that the endow-

ment effect is still significant in the matched sample after including time fixed effects in addition to firm fixed effects. The switch to full auctioning is estimated to decrease emissions growth, i.e. accelerate de-carbonization, by 19.6% during the first post-treatment year. However, in the second post-treatment year the effect becomes insignificant. Once installation-specific trends are included there is no longer evidence in favor of an endowment effect, even for small installations.

These results suggest the presence of a level effect. The level of emissions may have been higher than optimal with free allocation in place prior to 2013. With the advent of full auctioning emissions were adjusted downward through a temporary acceleration of the plants' de-carbonization rate during the first post-treatment period. Once the adjustment was completed emissions growth was no longer significantly different for plants subject to free allocation and full auctioning, respectively. Although the effect is not significant when employing the most demanding specification including plant-level trends, this result suggests the presence of a distortion in the behavior of small plants on account of free allocation, leading to higher than optimal emissions.

7 Summary and Conclusions

This paper evaluates whether a key property of cap-and-trade systems, the independence of allocations and emissions at the level of the affected unit, holds empirically for power plants regulated under the EU ETS. Independence is required for a cap-and-trade system to be cost-effective. However, it is challenging to analyze the causal relationship between allocations and emissions due to the endogeneity of allocations. The analysis in this paper overcomes the endogeneity issue by exploiting a natural experiment, which provides for exogenous variation in plant-level allocations: At the start of EU ETS Phase III free allocation was abandoned in favor of full auctioning for power plants in the EU-15 countries, whereas free allocation continues under a special rule for the benefit of plants in eight new EU members states, the so-called 10c rule.

I apply a matched diff-in-diff research design to a unique panel dataset containing plant-level emissions data and plant-level technical information. The dataset was constructed by matching emissions data from the EU Transactions Log (EUTL) with information on capacity, fuel type used and plant technology from the Platts power plant database. I conduct the regression analysis on both an unmatched sample and a matched sample

using a synthetic control group approach, both for the full sample of all plants and for a sub-sample of small plants with a capacity of up to 50 MW.

Regression results fail to find a significant endowment effect for the full sample once unobserved heterogeneity is controlled for through the inclusion of plant-level fixed effects, year fixed effects and plant-level trends. However, I find some limited evidence of a temporary causal relationship of allocations on emission for the sub-sample of small plants. Switching from free allocation to full auctioning is estimated to temporarily slow down the emissions growth of small installations. However, this effect is no longer significant in a demanding specification controlling for installation-level trends.

Based on the analysis so far I conclude that while independence appears to hold for the full sample of electricity sector plants, caution regarding the liberal application of free allocation may be warranted. If distortions exist for parts of the electricity sector, it stands to reason to infer that free allocation may also distort the behavior of plants less attuned to trading than power producers are. This may be especially true for manufacturing plants, which tend to be less active traders and under the EU ETS receive more generous endowments of emissions allowances than power plants do.

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