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THE JOINT IMPACT OF THE EUROPEAN UNION EMISSIONS TRADING SYSTEM ON CARBON EMISSIONS AND ECONOMIC PERFORMANCE

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On 3 May 2018, the OECD Council invited Lithuania to become a Member. At the time of preparation, the deposit of Lithuania's instrument of accession to the OECD Convention was pending and therefore Lithuania does not appear in the list of OECD Members and is not included in the OECD zone aggregates.

On 25 May 2018, the OECD Council invited Colombia to become a Member. At the time of preparation, the deposit of Colombia's instrument of accession to the OECD Convention was pending and therefore Colombia does not appear in the list of OECD Members and is not included in the OECD zone aggregates.

ABSTRACT/RÉSUMÉ

The joint impact of the European Union emissions trading system on carbon emissions and economic performance

This paper investigates the joint impact of the European Union Emissions Trading System (EU ETS), Europe's main climate change policy, on carbon emissions and economic performance of regulated companies. The impact on emissions is analysed using installation-level carbon emissions from national Polluting Emissions Registries from France, Netherlands, Norway and the United Kingdom complemented with data from the European Pollutant Release and Transfer Register (E-PRTR). The impact on firm performance is analysed using firm-level data for all countries covered by the EU ETS. A matching methodology exploiting installation-level inclusion criteria combined with difference-in-differences is used to estimate the policy's causal impact on installations' emissions and on firms' revenue, assets, profits and employment. We find that the EU ETS has induced carbon emission reductions in the order of -10% between 2005 and 2012, but had no negative impact on the economic performance of regulated firms. These results demonstrate that concerns that the EU ETS would come at a cost in terms of competitiveness have been vastly overplayed. In fact, we even find that the EU ETS led to an *increase* in regulated firms' revenues and fixed assets. We explore various explanations for these findings.

JEL classification codes: Q52, Q54, Q58

Keywords: EU Emissions Trading System, carbon emissions reductions, firm performance, competitiveness

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Impact conjugué du système d'échange de quotas d'émission de l'Union Européenne sur les émissions de carbone et la performance économique

Il s'agit d'étudier l'incidence que le système d'échange de quotas d'émission de l'Union européenne (SEQE-UE), pièce maîtresse de la politique européenne de lutte contre le changement climatique, a sur les émissions de carbone ainsi que sur la performance économique des entreprises soumises à réglementation. L'impact sur les émissions est analysé à la lumière des émissions de carbone par installation qui sont consignées dans les registres d'émissions polluantes tenus par la France, la Norvège, les Pays-Bas et le Royaume-Uni, que viennent compléter les données du registre européen des rejets et des transferts de polluants (PRTR). L'impact sur les résultats des entreprises est analysé à l'aide des données par entreprises disponibles pour l'ensemble des pays couverts par le SEQE-UE. On applique une méthode d'appariement, permise par les critères d'inclusion des installations, combinée à une méthode de différences des différences afin d'estimer l'incidence du dispositif sur les émissions des installations ainsi que sur le chiffre d'affaires, les actifs, les bénéfices et les effectifs des entreprises. Il en ressort que le SEQE-UE s'est accompagné d'une baisse des émissions de carbone d'environ 10 % entre 2005 et 2012, sans que la performance économique des entreprises soumises à la réglementation en pâtisse. Ces résultats montrent que la crainte que le SEQE-UE n'altère la compétitivité est largement exagérée. En réalité, la mise en place du SEQE-UE a fait *croître* le chiffre d'affaires et la valeur des actifs fixes des entreprises soumises à la réglementation. Ces conclusions trouvent diverses explications, qui sont étudiées ici.

Codes de classification JEL : Q52, Q54, Q58

Mots-clés : Système d'échange de quotas d'émission de l'UE, réductions des émissions de carbone, performance des entreprises, compétitivité

Table of contents

Tables

Figures

The joint impact of the European Union emissions trading system on carbon emissions and economic performance

By Antoine Dechezleprêtre, Daniel Nachtigall and Frank Venmans[1]

Executive summary

The European Union Emissions Trading System (EU ETS) is Europe's main policy to address climate change. This cap-and-trade mechanism requires over 14,000 energy-intensive plants across 31 European countries, belonging to around 8,000 companies and accounting for over 40% of the EU's total greenhouse gas emissions, to reduce their carbon emissions. Installation operators can freely trade carbon emissions permits with each other, ensuring that emissions reductions are achieved in a cost-effective manner. However, since the introduction of the Scheme, there have been concerns that the EU ETS would affect the competitiveness of the European industry by putting regulated companies at a disadvantage with respect to their foreign competitors.

This paper presents the first comprehensive, European-wide investigation of the impact of the EU ETS on carbon emissions and economic performance of regulated companies during the first two phases of the System's existence, from 2005 to 2012. The impact on emissions is analysed using installation-level carbon emissions data from national Polluting Emissions Registries from France, Netherlands, Norway and the United Kingdom complemented with data from the European Pollutant Release and Transfer Register (E-PRTR). The impact on firm performance is analysed using firm-level data for all countries covered by the EU ETS. A matching methodology exploiting installation-level inclusion criteria combined with difference-in-differences is used to estimate the policy's causal impact on installations' emissions and on firms' revenue, assets, profits and employment.

The paper finds that the EU ETS has induced carbon emission reductions of around -10% between 2005 and 2012. Most of the emission reduction was observed in the second trading phase of the EU ETS: the impact is -6% for the first phase and -15% in the second phase. The effect is strongest for larger installations, in line with the idea that pollution control is capital intensive and involves high fixed costs. While all sectors seem to have experienced a decline in their carbon emissions, the effect of the EU ETS appears to have been stronger in the chemicals, non-metallic mineral products and electricity sectors. Finally, we observe that a more generous allocation of free allowances translates into a lower impact of the EU

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ETS and that over-allocated installations have not reduced emissions. Our econometric model implies that, had all installations received only half of their pre-ETS emissions, then the impact of the EU ETS on emissions reduction would have been much larger at around -25%. This finding suggests that the impact of the EU ETS on CO2 emissions should increase in the years to come, independently of the total emissions cap, as fewer and fewer emissions allowances are allocated for free.

Turning to the impact on the economic performance of regulated firms, we find that, contrary to what could have been expected, the EU ETS led to a statistically significant increase in revenue and in fixed assets of regulated firms. At the same time, the EU ETS has not had any statistically significant impact on regulated firms' number of employees and profit. These findings suggest that the EU ETS induced regulated companies to increase investment – likely in carbon-saving technologies – which, in turn, may have increased productivity.

Exploring the heterogeneity of the impacts, there are only small differences across phases. Most importantly, we find that no single country or sector experienced a negative impact on revenue, fixed assets, employment or profits. This does not preclude the possibility that some individual firms in some specific countries or sectors may have been negatively affected, but these impacts are too narrow to be statistically detectable. The electricity and heat sector seems to have most benefited from the EU ETS, with statistically significant increases in revenue, assets, employment and return on assets, a finding which is compatible with windfall profits stemming from the combination of cost pass-through and free allocations. Within sectors considered at risk of relocation by the European Commission, companies regulated by the EU ETS performed relatively better than their non-ETS counterparts. This indicates that the distribution of free allowances may have more than compensated EU ETS firms at risks for the induced carbon abatement costs of the regulation.

We conclude from our analysis that the EU ETS in its first ten years of existence led to carbon emissions reductions without negatively affecting the economic performance of regulated firms and thus the competitiveness of the European industry. These results demonstrate that concerns that the EU ETS would come at a cost in terms of competitiveness of the European industry have been vastly overplayed. However, the overall stringency of the EU ETS has so far been relatively weak, as demonstrated by the low price of carbon permits on the market. Therefore, different impacts could be observed in the future, as the EU ETS cap becomes increasingly tighter.

1. Introduction

1. Emissions trading programs have assumed an ever more prominent role in environmental policy over the last few decades. In the US, the Acid Rain Program, the Regional Greenhouse Gas Initiative (RGGI), and California's cap-and-trade program are all examples of this trend. South Korea, New Zealand, Ontario and Quebec have all recently created their own cap-and-trade programs to regulate greenhouse gas emissions. China has initiated several pilot programs in anticipation of a national market that has been officially launched in the end of 2017. Japan, Brazil, Mexico, Thailand, Vietnam and Chile are individually making moves toward launching their own. Global carbon markets currently cover 4.6 billion tons of CO2 emissions, representing around 13% of global greenhouse gas emissions. Around 7 gigatonnes (Gt) of carbon emission allowances – representing a total value of €60 billion – were traded globally in 2016 (Reuters, 20016[1]). By the end of 2016, carbon emissions trading programs worldwide had generated close to USD 30 billion in public revenue by auctioning a share of their allowances (ICAP, 2017[2]). With so many new initiatives in the works, these numbers will grow much larger in years to come. China's national carbon market, for example, is expected to cover between 3 and 4 billion tons of CO2 annually - around 10% of the world's emissions in 2016.

2. At present, the European Union Emissions Trading Scheme (EU ETS) is the largest cap-and-trade program in the world. The EU ETS was launched in 2005, allocating tradable emissions permits to over 14 000 power stations and industrial plants in 31 countries, accounting for over 40% of the EU's total greenhouse gas emissions. Like all of the new emissions trading initiatives around the globe, the EU ETS was expected to reduce carbon emissions in a cost-effective manner, and to spur the development of new low-carbon technologies. However, right from the introduction of the Scheme, there have been concerns about its potential impacts on the competitiveness of regulated businesses. Indeed, economists traditionally think that environmental regulations add costs to companies and divert resources away from productive activities, thereby slowing down productivity. Some, therefore, expected the EU ETS to affect the competitiveness of the European industry, in particular since the stringency of climate change policies is lower outside Europe, putting companies regulated under the EU ETS at a disadvantage with respect to their foreign competitors. As a consequence, European businesses may move manufacturing capacity to countries with relatively laxer policies, causing policy-induced pollution leakage, as predicted by the pollution haven hypothesis (Levinson, A., and M. S. Taylor, 2008[3]).

3. An alternative view, articulated by Michael Porter (Porter, 1991[4]), is that environmental regulations such as the EU ETS might lead regulated firms and the economy as a whole to become more competitive internationally by providing incentives for environmentally-friendly innovation that would not have happened in the absence of policy. Both of these views have received much attention by policy makers, particularly in the recent context of economic downturn. Indeed, EU policy makers have often articulated their vision that the EU ETS would be a driving force of low-carbon innovation and economic growth (see, for instance, European Commission, (European Commission, 2005[5]), and European Commission, (European Commission, 2012[6])). Recent empirical evidence shows that the EU ETS has increased innovation activity in low-carbon technologies among regulated entities by as much as 30% compared to a counterfactual scenario (Calel, R. and Dechezleprêtre, A., 2016[7]), but this does not imply that the competitiveness of regulated companies has consequently improved.

4. In this paper, we conduct the first comprehensive, European-wide investigation of the impact of the EU ETS on carbon emissions and economic performance of regulated companies during the first two phases of the System's existence, from 2005 to 2012. The EU ETS offers a unique opportunity to investigate the causal impact of an environmental policy on firms' environmental performance and economic outcomes. As explained above, it is the first and largest environmental policy initiative of its kind anywhere in the world, which makes it an interesting case to study. But also important – from a statistical analysis point of view – is the fact that, in order to control administrative costs, the EU ETS was designed to cover only installations above a certain production capacity threshold. Installations falling below this threshold or firms operating these installations are not covered by EU ETS regulations, even though they can be very similar to the regulated entities. We can thus exploit these installation-level inclusion criteria to compare installations or firms operating in the same country and sector and of similar characteristics, but which have fallen under different regulatory regimes in 2005. This provides an opportunity to apply the sort of quasi-experimental techniques most suited to assessing the causal impacts of environmental policies (Greenstone, M. and Gayer, T. , 2009[8]; List, J. A., Millimet, D. L., Fredriksson, P. G., and McHone, W. W. , 2003[9])

5. In order to evaluate the causal impact of the EU ETS on carbon emissions, we use emissions data at the installation level from the national Pollution Release and Transfer Registers (PRTRs) of France, the Netherlands, Norway, and the United Kingdom. In contrast to most other European countries, the PRTRs of these four countries are characterized by a low reporting threshold for carbon emissions (below 10 kt per year) and therefore include data on many installations that are not covered by the EU ETS, which may offer a suitable control group against which to compare the emissions performance of regulated installations. For each carbon-emitting installation in these national PRTRs, we determine their regulatory status using the official European Union database on EU ETS-regulated facilities, the European Union Transaction Log (EUTL). We compare ETS and non-ETS installations both before and after the EU ETS started, applying a matched difference-in-differences study design that enables us to control for confounding factors which affect both regulated and unregulated installations (demand conditions, input prices, sector- and country-specific policies, etc.), as well as installation-level heterogeneity (Abadie, 2005[10]; Heckman, J., Ichimura, H., Smith, J., and Todd, P. , 1998a[11]; Heckman, J. J., Ichimura, H., and Todd, P. , 1998b[12]; Smith, J. and Todd, P. , 2005[13]). Our results are based on 240 pairs of EU ETS and similar non-EU ETS installations across the four countries. This sample size might look small but this is a usual feature of matching studies: by restricting the sample to installations that are closely comparable, one necessarily reduces the sample size, but to the benefit of accurately determining the policy impact.

6. We find that the EU ETS led to a statistically significant reduction of carbon emissions in the order of -10% in the first two trading phases between 2005 and 2012. Most of the emission reduction was observed in the second trading phase of the EU ETS: the impact is -6% for the first phase and -15% in the second phase. The effect is strongest for larger installations, in line with the idea that pollution control is capital intensive and involves high fixed costs. While all sectors seem to have experienced a decline in their carbon emissions, the effect of the EU ETS appears to have been stronger in the chemicals, non-metallic mineral products and electricity sectors. Finally, we observe that a more generous allocation of free allowances translates into a lower impact of the EU ETS and that over-allocated installations have not reduced emissions. Our econometric model implies that, had all installations received only half of their pre-ETS emissions, then the impact of the EU ETS on emissions reduction would have been much larger at around -

25%. This finding suggests that the impact of the EU ETS on CO2 emissions should increase in the years to come, independently of the total emissions cap, as fewer and fewer emissions allowances are allocated for free.

7. To evaluate the impact of the EU ETS on firm performance, we use a newly constructed data set combining the EUTL with financial data from Orbis, which records key firm characteristics, including sector of activity, revenue, assets, profits, number of employees, and regulatory status with respect to the EU ETS. Our data set includes information on over 1 million firms across 31 countries. We identify over 8,200 firms operating more than 14 000 installations regulated under the EU ETS, accounting for over 99% of EU ETS-wide emissions. Using this data set, we are able to compare unregulated and would-be regulated firms both before and after the EU ETS launched. Our matching procedure allows us to construct a group of 1,787 EU ETS firms matched with the closest non-EU ETS firms operating in the same country and sector and similar in all observed characteristics to EU ETS firms prior to the introduction of the policy. This control group enables us to assess the causal impact of the EU ETS on firm performance by providing a counterfactual – a group of firms which likely mimics how EU ETS firms would have evolved, had they not become regulated.

8. We find that, contrary to what could have been expected, the EU ETS led to a statistically significant increase in revenue (by 7% to 18% depending on the specification) and in fixed assets (by 6% to 10%) of regulated firms, and this result is remarkably robust to various sensitivity tests. At the same time, the EU ETS has not had any statistically significant impact on regulated firms' number of employees and profit. These findings suggest that the EU ETS induced regulated companies to increase investment – likely in carbon-saving technologies – which, in turn, may have increased productivity. We conclude from our analysis that the EU ETS led to carbon emissions reductions without negatively affecting the economic performance of regulated firms and thus the competitiveness of the European industry.

9. The paper contributes to the growing empirical literature on the joint impacts of environmental policies, and of climate change policies in particular, on environmental and economic performance. Overall, this nascent literature shows that environmental regulations tend to improve environmental performance while not weakening economic performance (Dechezleprêtre and Kruse, 2018[14]). The literature focusing on the competitiveness effects of environmental regulations has found that environmental policies can lead to statistically significant adverse effects on trade, employment, plant location and productivity in the short run, in particular in a well-identified subset of pollution- and energy-intensive sectors, but that these impacts are small and temporary relative to general trends in production (Dechezleprêtre, A. and Sato, M., 2017[15]).

10. The paper proceeds as follows. Section 2 presents some background information on the EU ETS and provides some description of emissions trends. Section 3 surveys the evidence on the impact of the EU ETS on carbon emissions and economic performance. In section 4 we present a causal analysis regarding the impact of the EU ETS on carbon emissions using installation level data. In section 5 we estimate the impact of the EU ETS on the economic performance of regulated firms based on financial data. Section 6 concludes by considering some of the potential policy implications of our findings, and directions for future research.

2. Background on the EU ETS and trends of GHG emissions

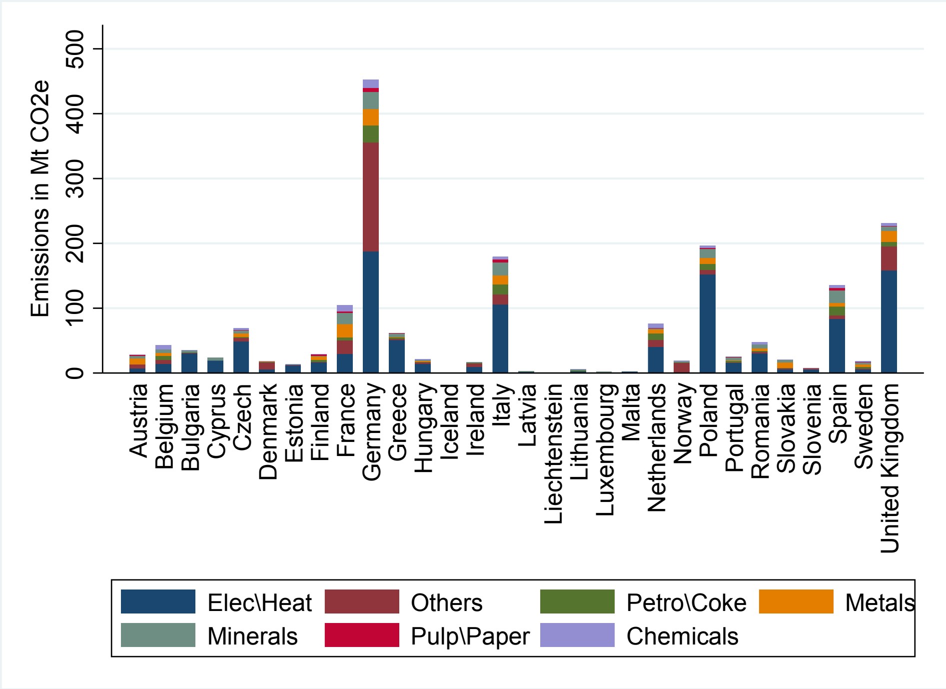
11. The EU ETS was launched in 2005. It currently covers 31 countries across Europe (all 28 European Union Member States plus Iceland, Liechtenstein and Norway). Currently, the EU ETS covers around 14,000 power stations and industrial facilities, representing roughly 40% of the EU's total greenhouse gas emissions, which are regulated according to their main activity, e.g. "combustion of fossil fuel", "cement production", "paper and pulp production". An important feature of the EU ETS is that not all carbon-emitting installations operating in these sectors are regulated, in order to minimize administrative costs. Activity-specific capacity criteria determine which installations are included in the EU ETS and which installations are exempt from the regulation. For instance, only combustion installations with a rated thermal input exceeding 20 MW are covered; steel plants are included if their production capacity exceeds 2.5 tons per hour; etc.[2] As in any cap-and-trade system, at the end of each year EU ETS installations are required to surrender as many permits as they emit GHG-emissions. Prior to the compliance date, installation operators can freely trade permits with each other (as well as with financial intermediaries and private citizens).

12. Figure 01 displays the emissions for each country by sector in the year 2012. We highlight the six sectors with the highest total emissions: Electricity and heat; petroleum refining and coke production; metals including iron and steel; chemicals; pulp and paper; and non-metallic minerals, with all other sectors grouped in a seventh category.[3] Together, these six sectors account for 82% of the aggregate emissions of the EU ETS.

[2] Some EU air pollution regulations use similar criteria for inclusion, but they were implemented at earlier dates.

[3] To determine the sector of activity of installations, we match installation data from the EUTL data with firm-level data from Orbis and obtain the activity codes of the respective mother company in the NACE classification. See Section 4 for details.

Figure 01. CO2 emissions by sector and country



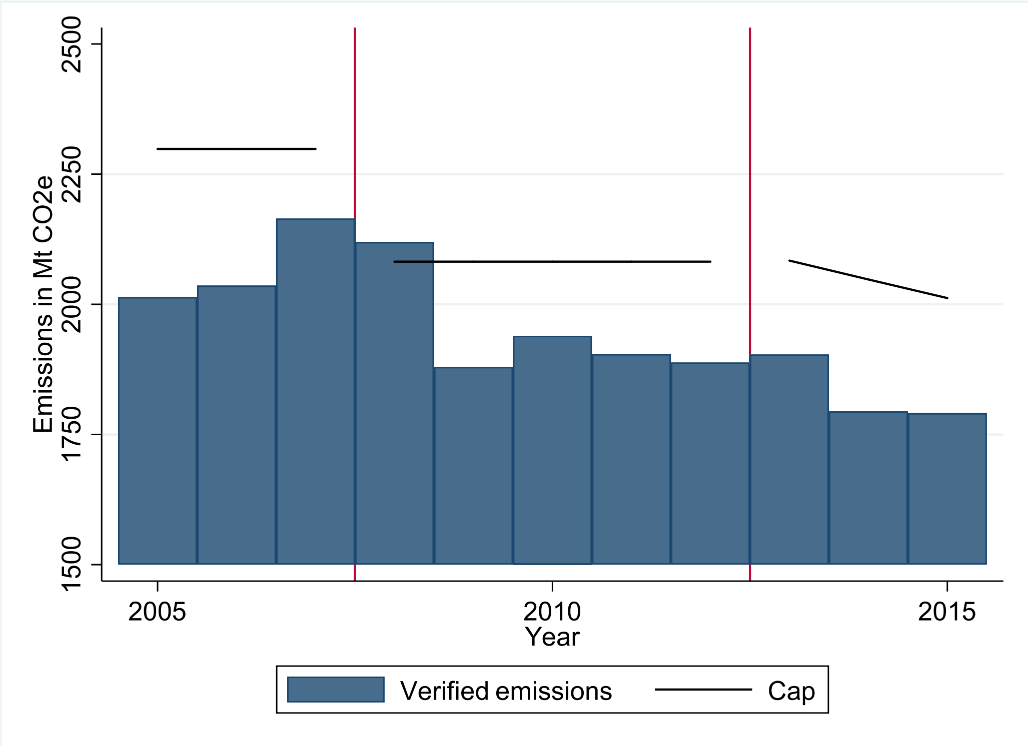
Source: EUTL, own calculations.[4]

13. With around 450 Mt CO2e per year, Germany accounts for almost one quarter of all EU ETS emissions. After Germany, the United Kingdom (231 Mt), Poland (196 Mt), Italy (179 Mt) and Spain (134 Mt) are the next largest emitting countries. The electricity and heat production sector tends to be the largest contributor to CO2 emissions in most countries, accounting for more than 50% of all emissions in the EU ETS.

14. The EU ETS has been divided into a number of trading phases, with successively more stringent emissions caps for each phase. For the first phase, the emissions cap was fixed at 2,298 Mt CO2e per year. Figure 2 plots the emission caps along with the verified emissions over time of all regulated installations based on the emissions data from the European Union Transaction Log (EUTL), the European Commission's centralized carbon emissions inventory which records emissions of all regulated installations. As can be seen from Figure 2 the verified emissions of installations covered by the EU ETS have been declining over time. One of the objectives of this paper is to understand whether this decrease can be attributed to the EU ETS or whether it is the result of a longer lasting trend.

[4] Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Figure 2. Overall cap and verified emissions from EU ETS installations 2005-2015



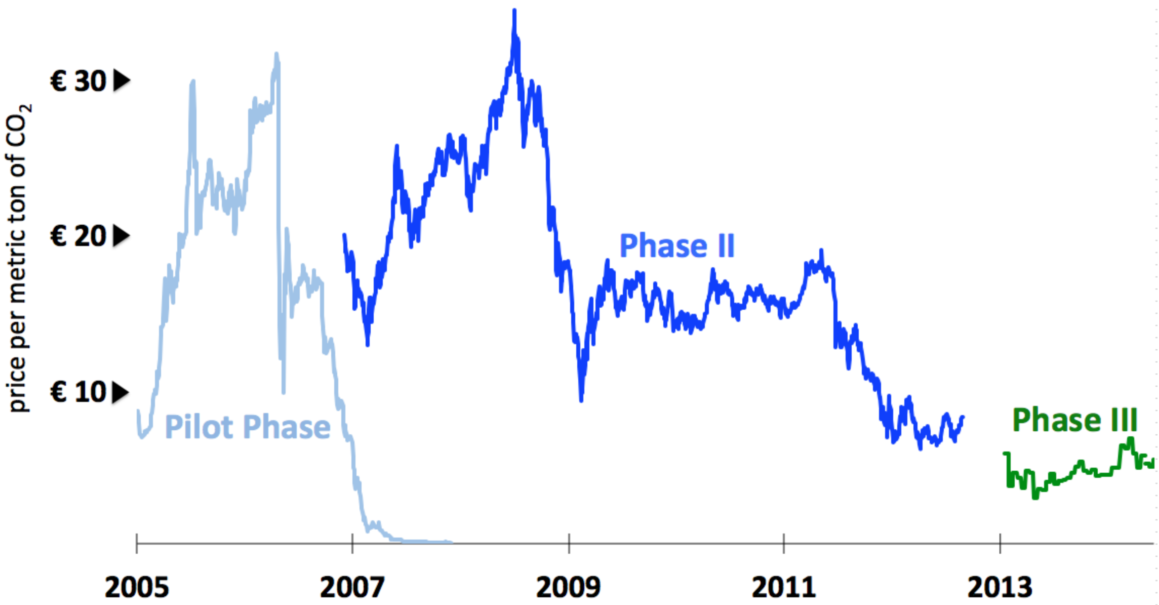
Source: EUTL, own calculations

15. Phase 1, running from 2005–2007, was insulated from later phases by prohibiting banking and borrowing of permits across the phase boundary. Figure 2 clearly indicates an oversupply of permits in the first phase, which is why the permit price approached zero at the end of the first trading period (see Figure 3). Phase 2 (2008–2012) and Phase 3 (2013–2020) allow firms to bank unused permits for later use, as well as a limited form of borrowing against future emissions reductions. This explains why the price has remained above zero despite over allocation, and also why verified exceeded the cap in 2008. With Phase 3, the coverage of the EU ETS also became broader and previously unregulated sectors such as aviation and the production of aluminum became regulated.[5]

16. Figure 3 presents the price of EU ETS allowances between 2005 and 2015. The average spot price in this period was around €10-15, but has varied between €0 and €30. In the third phase, the spot price has ranged between €5-7. However, the price of forward contracts has remained steadily above the spot price, suggesting firms are taking the progressive stringency of the cap into account. Installations, or rather the firms that operate them, can then make abatement and investment decisions according to the carbon price revealed in the market.

[5] Ellerman et al. (2010) give a more comprehensive review of the design and implementation of the EU ETS.

Figure 3. Price of EU ETS allowances 2005-2015



Source: European Environment Agency and Intercontinental Exchange.

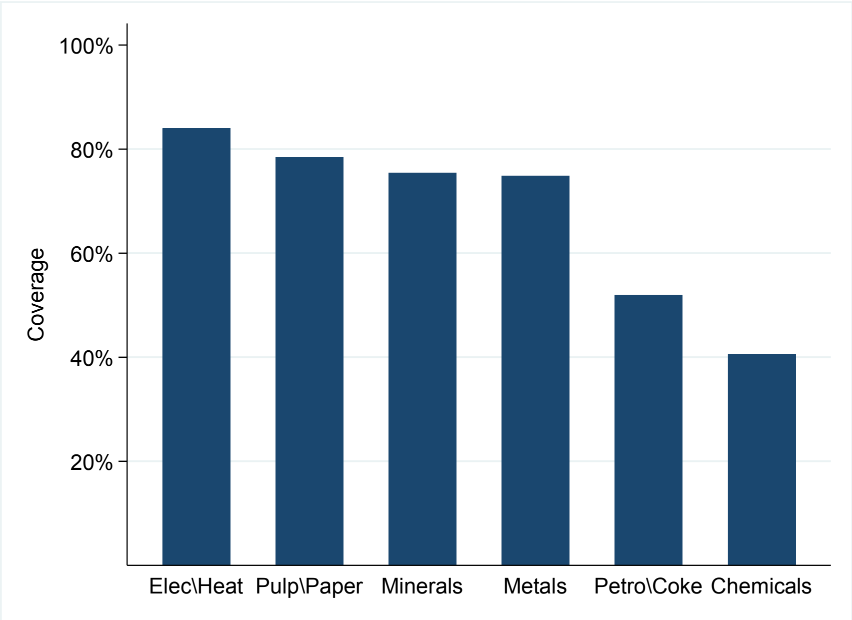
17. Is the declining trend in emissions observed in Figure 2 a consequence of the EU ETS? Since the EUTL does not include emissions data before the introduction of the EU ETS, we use data from the national GHG inventory of the United Nations Framework Convention on Climate Change (UNFCCC) which provides carbon emissions data at the sector level for all Annex I countries from 1990 to 2014. Under the UNFCCC, each country is required to report its national greenhouse gas inventory on an annual basis according to a standardized methodology developed by the Conference of the Parties (COP)[6] which makes inter-country comparisons possible. The inventory report covers all emissions and removals of direct GHGs at a disaggregated sectorial approach. We retrieve emissions from the six sectors with the highest emissions presented in Figure 01.[7]

18. Merging the UNFCCC emissions with the data from the EUTL allows us to calculate the sector-specific EU ETS coverage rates. These are displayed in Figure 4. The electricity and heat sector has the highest coverage rate by the EU ETS with 82% of emissions regulated. This is followed by the pulp and paper sector (78%) and the mineral sector (75%) while the chemical sector displays the lowest coverage rate with 42%. As is clear from Figure 4, the EU ETS only covers a part of each sector's emissions, implying that there exist many installations which are not covered by the EU ETS and, thus, can serve as a potential control group in the causal analyses presented in Sections 4 and 5.

[6] For the latest guidelines, see here: http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

[7] Table A.1 in the Appendix shows the sector name, the UNFCCC code and the corresponding NACE Rev. 2 code.

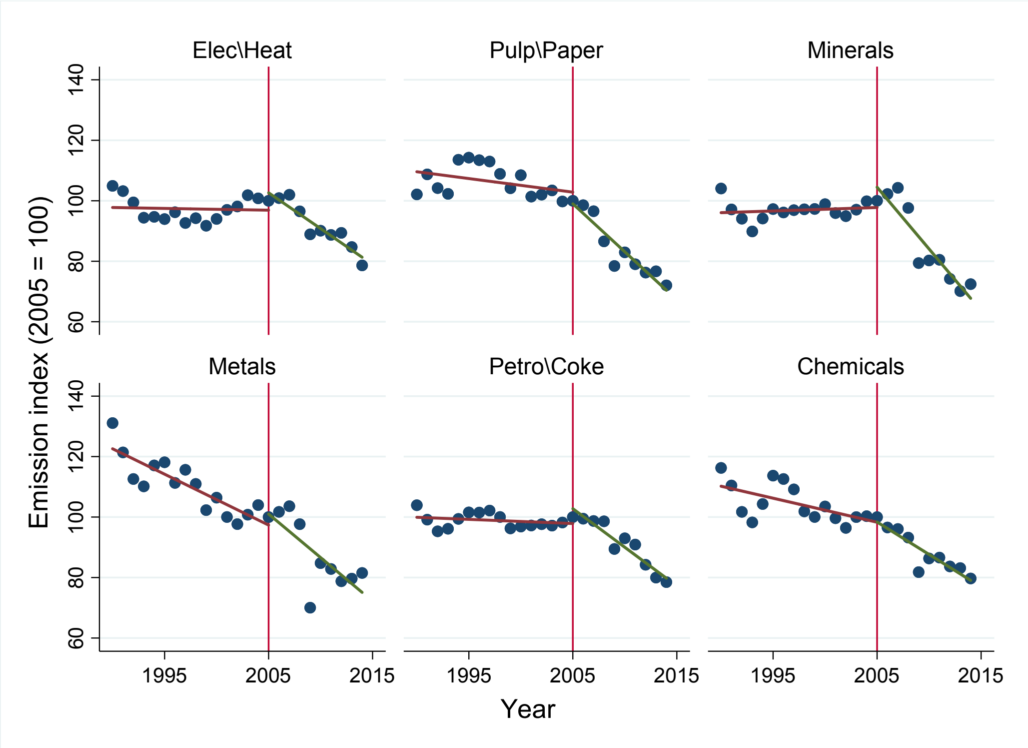
Figure 04. Coverage rate of EU ETS for specific sectors



Source: EUTL and UNFCCC, own calculations.

19. Figure 5 presents the trend in emissions in the six main sectors covered by the EU ETS. To compare the sectors with each other, we normalize emissions in the year 2005 to 100. Figure 5 suggests that emissions have been declining more rapidly after the implementation of the EU ETS in each and every sector. However, we cannot claim that the EU ETS has been causing this decline in emissions because it could have been driven by other factors, particularly by the global financial crisis in 2009. Indeed, a structural break in emissions trends seems to happen around the time of the financial crisis in all sectors. To shed more light on the causal impact of the EU ETS on emissions reductions, Section 4 presents an analysis based on installation-level data. But first, we review the empirical literature on the impact of the EU ETS.

Figure 05. Emission trends by sectors



Note: Sectors ordered according to coverage rate.
Source: UNFCCC, own calculations.

3. Previous literature on the impacts of the EU ETS

3.1. Impact on carbon emissions

20. The major objective of the EU ETS is to reduce CO2 emissions. By construction, any cap-and-trade system should be effective in reducing CO2 emissions in the covered sectors and regions as long as it is enforced and the cap is set tightly enough. However, observing emissions to be decreasing does not necessarily mean that the EU ETS is the cause of this decrease because there could have been emission reductions also in the absence of the EU ETS, e.g. due to technological progress or macroeconomic factors such as business cycle fluctuations. Thus, in order to assess the effectiveness of the EU ETS, one would need to know the counterfactual emissions, i.e. the emissions that would have been observed under business-as-usual (BAU).

21. Martin et al. (Martin, R., M. Muûls, and U. J. Wagner, 2016[16]) review the literature on ex-post evaluation of the EU ETS on emission reductions and classify three different approaches to estimate BAU emissions: estimates based on aggregate emissions, estimates based on emission data at the firm or plant level and qualitative studies based on interviews.

22. Aggregated emissions at the sectorial level have been used to estimate the counterfactual BAU emissions for the post-2005 period. Ellerman and Buchner (Ellerman, A. D., & Buchner, B. K., 2008[17]) extrapolate emissions from the National Allocation Plans (NAPs), while accounting for GDP and emission intensity to estimate BAU emissions for the first trading period of the EU ETS. They estimate the CO2 emissions to be reduced by

between 100 and 200 million tons across all EU ETS sectors and countries for the period from 2005 to 2006, which is equivalent to an abatement rate between 2.4 and 4.7 percent. Focusing on Germany, Ellerman and Feilhauer (Ellerman, A. D., and S. M. Feilhauer., 2008[18]) use the same methodology as Ellerman and Buchner (Ellerman, A. D., & Buchner, B. K., 2008[17]) and find that abatement per year was nearly 5 percent for all EU ETS sectors in the first trading phase. While the industrial sector experienced a 6.3 percent reduction, the power sector reduced its emissions by 4.1 percent. However, an important limitation of these studies is that NAP data lacks verification by authorities in many cases and is not perfectly comparable across countries because different countries employed different calculations and base years (Martin, R., M. Muûls, and U. J. Wagner, 2016[16]).

23. Anderson and Di Maria (Anderson, B., & Di Maria, C., 2011[19]) use Eurostat as a data source to estimate the impact of the EU ETS. Eurostat collects data on GHG emissions for several industry sectors based on energy data. They match this data to the corresponding ETS-sectors and account for industrial production, energy production, energy prices as well as information on temperature and precipitation. Using a dynamic panel model, the overall abatement of the first phase of the EU ETS (2005 – 2007) is estimated to be 247 Mt. CO2, equivalent to a 2.8 percent reduction.

24. Ellerman et al. (Ellerman, A. D., Convery, F. J., and de Perthuis, C. , 2010[20]) use the common reporting formats of the United Nations Framework Convention on Climate Change (UNFCCC) as a third data source in order to proxy historical emissions of EU ETS sectors and to estimate BAU-emissions for the first phase of the EU ETS. They estimate overall emission reductions between 2005 and 2007 to be 210 Mt. CO2, which is equivalent to an abatement rate of 3 percent. Taking the same approach, Egenhofer et al. (Egenhofer, C., M. Alessi, N. Fujiwara, and A. Georgiev., 2011[21]) extend this analysis by estimating emission reductions for the first two years of the second trading period (2008 – 2009). They find that the EU ETS improved the overall emission intensity by 3.35 percent on average, while this figure drops to 0.45 percent for the manufacturing sectors only.

25. Both Anderson and Di Maria (Anderson, B., & Di Maria, C., 2011[19]) and Ellerman et al. (Ellerman, A. D., Convery, F. J., and de Perthuis, C. , 2010[20]) estimate the abatement rate to be around 3 percent in the first phase. However, they emphasize that abatement has been very heterogeneous across countries. While most abatement occurred in the EU15 countries, Eastern European countries only slightly reduced their emissions.

26. Accounting for around 50% of the emission within the EU ETS, the power sector plays a crucial role in abatement. However, most studies that aim at analysing the impact of the EU ETS on emission reductions in this sector are forced to make use of simulations rather than ex-post analysis because of the scarcity of disaggregated data and the complexity of the European electricity market (Delarue, E., K. Voorspools, and W. D'haeseleer. , 2008[22]; Delarue, E. D., A. D. Ellerman, and W. D. D'haeseleer. , 2010[23]).

27. Using aggregated data on the country or sector level produces estimates on economy- or sector-wide effects which can be communicated very easily, but cannot claim any causality and suffers from aggregation errors. Instead the use of firm-level data solves these problems. McGuiness and Ellerman (McGuinness, M., and A. D. Ellerman., 2008[24]) use power plant-data from the UK in order to estimate the effect of the EU ETS on abatement for the first phase. Based on a fuel switching model, they estimate that natural gas utilization increased by about 22 percent while coal utilization decreased by 17 percent, resulting in annual emission reductions between 13 and 21 Mt CO2.

28. Four studies to date have used installation-level data to provide causal estimates of the effect of the EU ETS on regulated installations' carbon emissions, respectively in France, Germany, Norway and Lithuania. Using plant-level data for around 9 500 French manufacturing firms, Wagner et al. (Wagner, U. J., M. Muûls, R. Martin, and J. Colmer , 2014[25])show that ETS-regulated manufacturing plants in France reduced emissions by an average of 13% compared to a control group of similar but unregulated installations, suggesting that the EU ETS was effective at reducing carbon emissions of regulated plants. All of the impact occurs during Phase II, a period during which allowance prices fluctuated between €15 and €30. Petrick and Wagner (Petrick, S. and U. J. Wagner, 2014[26]) analyse the causal impact of the EU ETS on German manufacturing plants using comprehensive panel data from the German production census. They find evidence that phase II of the EU ETS caused treated plants to reduce their emissions by around 25% compared to untreated plants. Klemetsen et al (Klemetsen, M. E., K. E. Rosendahl, and A. L. Jakobsen , 2016[27]) examine the impacts of the EU ETS on the environmental and economic performance of Norwegian plants using plant-level data from the Norwegian Environment Agency for the period 2001 to 2013. They find some evidence that regulated plants reduced emissions by a large amount (-30%) in the EU ETS' second phase, but no evidence that emission intensity decreased in any of the Phases. Finally, Jaraite and Di Maria (Jaraite, J. and C. Di Maria , 2016[28]) analyse the impact of the EU ETS on CO2 emissions and economic performance in Lithuania for the period 2005-2010 using plant-level data. They find no reductions in emissions and a slight improvement in emissions intensity in 2006-2007.

3.2. Impact on economic activity

29. The introduction of carbon pricing in Europe generated wide concerns about the potential cost burden on industry. Model-based studies predicted that with carbon prices around €20-€30/tCO2 the marginal cost impacts would be small for the large majority of industrial activities, but large impacts could occur in upstream segments within several energy intensive sectors, including fertilizers, iron and steel, aluminum, paper, basic organic chemicals or coke oven production (Sato, M., Neuhoff, K., Graichen, V., Schumacher, K., & F. Matthes, 2014[29]). However, evidence suggests that most sectors did not see high cost increases due to a combination of generous free allocation and low carbon prices. In the electricity sector, where marginal costs were affected, high levels of carbon cost pass-through were observed, as theory would predict. Chan et al. (Chan, H., S. R. Li, S. and F. Zhang, 2013[30]) compare 5 873 regulated and non- regulated firms between 2001 and 2009 across 10 European Union countries in the power, cement and iron and steel sectors. In the power sector, regulated firms on average experienced an increase in 'material costs' (including fuel) by 5 percent and 8 percent during Phase I and II of the European Union Emissions Trading System (EU ETS). However, this may be due also to the European Union renewable energy target. Moreover, no such effects are found for the cement and steel sectors, because emissions trading permits were largely allocated to these sectors for free during this period.

30. A number of studies have examined the impact of the EU ETS on employment, and there is no evidence that the EU ETS might have negatively affected the economic performance of regulated firms (Martin, R., M. Muûls, and U. J. Wagner, 2016[16]). Anger and Oberndorfer (Anger, N. and Oberndorfer, U., 2008[31]) compare EU ETS firms with each other, using the allocation factor (the ratio between allowances allocated for free and verified emissions) as an indicator of the stringency of the regulation at the firm level. They find no evidence of an impact of the allocation of EU emissions allowances on firm employment. Commins et al. (Commins, N., Lyons, S., Schiffbauer, M. and Tol, R. S.,

2011[32]) use a large sample (200,000 firms) to study the impact of the EU ETS on employment and productivity between 1996 and 2007. They find a negative effect of the EU ETS on total factor productivity growth of around 3% and a positive impact on employment of around 1.5%. The main caveat of this study is that the treatment status of a firm was determined at the sector level, i.e. firms with small installations were incorrectly labelled as treated although only large installations in the sector were subject to regulation. Therefore, the estimated EU ETS effects included the impact of sector level shocks to the outcome variables which were unrelated to the EU ETS.

31. Abrell et al. (Abrell, J., Faye, A. N., and Zachmann, G. , 2011[33]) use a better methodology. They estimate the impact of the EU ETS on regulated firms by matching each EU ETS firm with a similar firm - based on observable firm characteristics - in a non-EU ETS sector. In the period between 2004 and 2008, they find a statistically significant, slight decrease in employment at EU ETS firms of 0.9%. This result is driven by the non-metallic minerals sector. However, as the authors acknowledge, taking control firms only from non-regulated sectors is problematic because of the possible non-random selection of which sectors were regulated under the EU ETS. For this reason, the study is likely to suffer from selection bias at the sector level. Chan et al. (Chan, H., S. R. Li, S. and F. Zhang, 2013[30]) estimate the impact of the EU ETS on economic outcomes by comparing firms regulated under the EU ETS with unregulated firms in three sectors: cement, steel and power production. They cannot determine the sign of the effect with confidence for any of the three sectors analysed.

32. Marin et al (Marin, Pellegrin and Marino, 2017[34])empirical evaluate the effect of the EU ETS on multiple measures of economic performance at the firm level: value added, turnover, employment, investment, labour productivity, total factor productivity and markup. Their data includes 792 firms regulated by the EU ETS. They apply a difference-in-differences method with pre-treatment matching (the same method that is used in this paper) but, because their data covers only a small share of EU ETS firms, it is possible that the control group includes regulated companies, which would lead to biased estimates of the treatment impact. They find that the EU ETS has increased employment among treated firms by 8%, investment by 26% and turnover by 15%. Value added increased slightly less than turnover (6%), suggesting that the EU ETS, while driving up sales, also increased material and other variable costs. No significant effect on average wages and labour productivity is found, while the authors find negative effects on TFP, profitability and markups, although of a small magnitude (respectively -2%, -0.5% and -1.5%).

33. The four studies mentioned in Section 3.1, which have used installation-level data to analyse the causal effect of the EU ETS on regulated installations' carbon emissions, also looked at various economic performance outcomes. In France, Wagner et al. (Wagner, U. J., M. Muûls, R. Martin, and J. Colmer , 2014[25]) do not find any statistically significant impact on employment or value added but they report a large impact on investment in Phase II. In Germany, Petrick and Wagner (Petrick, S. and U. J. Wagner, 2014[26]) did not find any statistically significant impact on employment. In Norway, Klemetsen et al (Klemetsen, M. E., K. E. Rosendahl, and A. L. Jakobsen , 2016[27])) find statistically significant increases in both value-added and labor productivity. These effects could come from the impact that free allowances or cost pass-through may have had on value added. Finally, in Lithuania, Jaraite and Di Maria (Jaraite, J. and C. Di Maria , 2016[28]) find no statistically significant impacts of the EU ETS on firms' profitability.

34. Overall, therefore, only a handful of studies have used micro-data and quasi-experimental techniques to analyse the causal effect of the EU ETS on regulated firms'

economic and environmental performance. However, with the exception of Marin et al (Marin, Pellegrin and Marino, 2017[34]) these studies have looked at different countries individually, two of them with a very small number of covered installations. They have also looked at different outcome variables based on data availability. Our goal in this paper is to conduct a more systematic analysis of the impact of the EU ETS on firms' economic and environmental performance on the largest possible sample.

4. The causal impact of the EU ETS on carbon emissions

35. The descriptive analysis presented in Section 2 does not allow for establishing a causal relationship between the implementation of the EU ETS and the reduction of emissions. In fact, the structural break in the emissions trend observed on Figure 5 might have been caused by other factors than the EU ETS, such as the global financial crisis. In order to establish a causal link between EU ETS and carbon emissions, we make use of installation-level data while exploiting a special design feature of the EU ETS, namely the sector-specific capacity thresholds. By comparing installations whose production capacity is above the inclusion threshold (and therefore became regulated) with those that are below the threshold, but are otherwise similar, we can construct a quasi-experimental design setting which allows for assessing the causal impact of the EU ETS.

4.1. Data and descriptive statistics

36. In our analysis, we make use of data from several national Pollution Transfer and Release Registers (PRTR). Since the 1990s, PRTRs were established in most European countries to monitor the releases of specific pollutants to air, water and soil at the installation level, covering a wide range of industrial activities such as power generation, manufacturing, and waste treatment. Beginning in 2001, large installations also had to report their pollutant releases to the Europe-wide register (EPER, later E-PRTR).[8] The E-PRTR currently covers more than 30,000 installations that annually report their releases of 91 key pollutants including heavy metals, pesticides and greenhouse gases such as carbon dioxide (CO2).

37. Identifying the causal impact of the EU ETS on carbon emissions requires data on emissions for the period before and after the introduction of the EU ETS, and for both regulated installations and unregulated installations which can serve as a control group to estimate how EU ETS installations would have behaved, had they not been regulated. However, the E-PRTR is not well suited for this exercise because only installations emitting more than 100 kilo tonnes (kt) of CO2 per year are required to report their emissions. This very high reporting threshold means that almost all installations which report CO2 emissions to the E-PRTR will be covered by the EU ETS, leaving us with very few unregulated installations to serve as a comparison group. Therefore, we collected data from the national PRTRs of France, the Netherlands, Norway, and the United Kingdom, which have lower reporting thresholds (see Table 1) and complemented this dataset with E-PRTR data for these countries. All other national PRTRs have a reporting threshold for CO2 emissions equal to that of the E-PRTR and would therefore not be suitable to analyse the impact of the EU ETS.

[8] In 2007, the European Pollution Transfer and Release Register (E-PRTR) replaced the European Pollutant Emission Register (EPER) that was enacted in 2001.

Table 1. Characteristics and coverage of national PRTR datasets

Country	Coverage since	Reporting threshold	# Installations with reported CO_2 emissions	# Installations covered by ETS
France	2003	10 kt	1,694	927
Netherlands	1990	< 1 kt	1,601	247
Norway	1997	< 1 kt	499	113
United Kingdom	1998	10 kt	3,295	522

38. It is important to keep in mind for the remainder of the analysis that data constraints lead us to focus on four countries only. How representative are these countries of the EU ETS as a whole? Table 2 indicates that installations in the four countries of our analysis only show slightly different patterns relative to the whole population of EUTL installations. Both country groups have similar average and median emissions, and the distribution of emissions and of the number of installations across shows a broadly similar pattern. This suggests that the sample of countries that we focus on might provide a reasonable indication of what the broader impact of the EU ETS across Europe may have been, even if we stress that the validity of our findings cannot strictly speaking be extended beyond the four countries of focus.

Table 2. Comparison of the four analysed countries with all countries in the EUTL

Variable	4 countries of analysis	All countries
Verified emissions		
Mean	192,952	179,423
Median	16,946	13,369
Share of verified emissions by sector		
Chemicals	4.0%	2.9%
Minerals	6.2%	9.0%
Basic Metals	11.0%	7.9%
Electricity	52.4%	54.1%
Other	26.4%	26.1%
Share of installations by sector		
Chemicals	5.0%	4.1%
Minerals	8.9%	14.5%
Basic Metals	1.8%	3.0%
Electricity	14.2%	26.8%
Other	70.2%	51.6%

39. Except for France, neither the national PRTRs nor the E-PRTR provide information on whether or not an installation is covered by the EU ETS. Hence, we retrieved data from the EUTL (which lists all EU ETS regulated facilities) and established a link between the EUTL and PRTR installations based on zip code, address, and installation name using string matching algorithms complemented with extensive manual verification.[9]

40. Using the EUTL data allows us to validate the accuracy of self-reported PRTR emissions, at least for regulated installations. We expect the emissions in the EUTL to be accurate because emissions are carefully monitored and verified by third-party auditors and by the regulating authorities. The coefficient of correlation between self-reported emissions in the PRTR and verified emissions in the EUTL is 0.989 based on 8,944 installation-year

[9] We made use of the STATA package 'reclink'.

observations, indicating a very good quality of the PRTR data. It is worth noting that installations not regulated by the EU ETS are not subject to the independent verification of emissions as is the case with the EU ETS. Therefore, some measurement error might be present for non-ETS installations, because they should not be expected to devote resources to calculating their emissions as accurately as ETS installations. However, this would only be a problem for the analysis if non-ETS installations would have an incentive to systematically under-report their emissions after the introduction of the EU ETS, which is highly unlikely since they do not face any carbon regulation. The presence of measurement error, therefore, could just make our estimates less precise, if anything.

41. While the Dutch, Norwegian, and UK PRTRs report directly the CO2 emissions from the combustion of fossil fuels, the French PRTR distinguishes between total CO2 emissions and CO2 emissions from biofuels. We take the difference between total and biofuel emissions as the relevant emission value for French installations because the regulation of the EU ETS sets the emission factor of biomass to zero, meaning that installations do not need to surrender any allowances for emissions originating from the combustion of biofuels.[10] Cross-checking with the EUTL data reveals that this difference coincides in almost all cases with the verified emissions in the EUTL data. To improve the data quality we remove installation-year observations that we considered as unrealistic. This includes in particular ‘spikes’, i.e. emissions of an installation that fall by more than a certain factor from one year to the other, but increase by more than the same factor in the subsequent year or vice versa.[11]

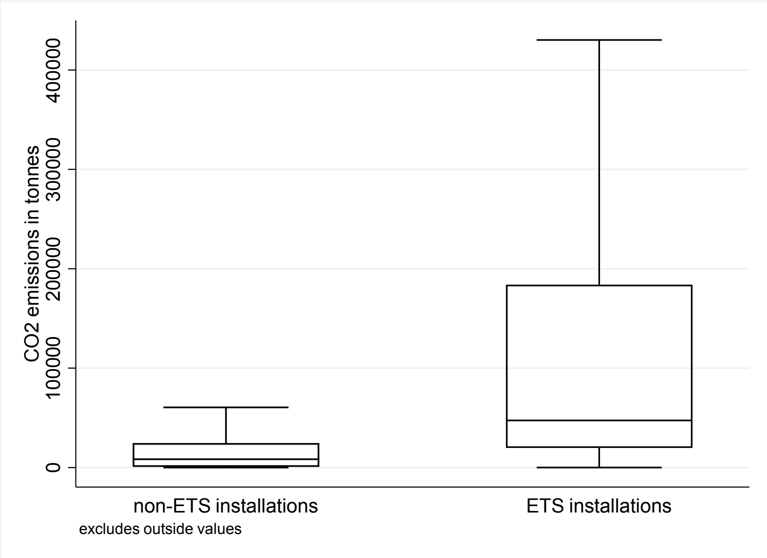
42. At present, we only use data for the first and the second trading period because the coverage of the EU ETS broadened substantially in 2013 with the beginning of the third trading phase, leaving only few control observations in some sectors. Our final dataset comprises 1,828 regulated installations and 5,258 unregulated ones. However, regulated and non-regulated installations are very different from each other due to the construction of the EU ETS. Since regulated installations are relatively large by construction of the ETS, this also translates into higher emission values. In fact, the average emissions of ETS installations are more than ten times higher than emissions of non-EU ETS installations before the implementation of the EU ETS. Figure 6 shows the distribution of emissions for both types.

43. One could easily imagine that some unobserved shocks such as price spikes for fossil fuels would affect both types of installations in a systematically different manner. To address this shortcoming, we would like to base our analysis on ETS and non-ETS installations which are very similar to each other before the EU ETS was launched, and compare an installation whose capacity is slightly above the regulation inclusion threshold with an installation whose capacity is slightly below. Unfortunately, we do not observe the capacity, but we can use the combination of sector and pre-ETS emissions as proxy for capacity. Figure 6 indicates that there is some overlap between both regulated and non-regulated installations, particularly for installations with annual emissions lower than 50kt. Clearly, we will not find adequate control installations for large power plants or refineries. Once we restrict our sample to relatively comparable installations, the comparison is likely to yield more accurate estimates of the impact of the EU ETS. In the following, we explain the matching procedure in greater detail.

[10] See Annex IV of Directive 2003/87/EC.

[11] We somewhat arbitrarily chose the factor to be the 95% percentile of the distribution of spikes, equivalent to a value of 3.74, but check robustness of the results to alternative factors.

Figure 6. Distribution of emissions for ETS and non-ETS installations



4.2. Matching

44. Ideally, we would like to compare installations that are similar in all dimensions prior the implementation of the EU ETS so that it becomes difficult to explain away any difference in the outcome by other factors than the EU ETS. Since our dataset does not include data neither on capacity nor on actual output, we use pre-ETS emissions as a proxy for both. More precisely, we match each ETS installation to one or more non-ETS installation based on the mean of pre-ETS emissions as well as on the pre-ETS emission growth rate in order to account for emissions trends that were already present before the ETS was launched. Additionally, our data contains information on the country and the economic sector in which installations operate. Matching exactly on both ensures that installations are subject to very similar regulatory environments (other than the EU ETS) and face similar economic environments (demand conditions, input prices, etc.).

45. Taken together, we match on the log of average pre-ETS emissions, the emissions growth rate as well as exactly on the country and on the 3-digit level of the NACE Rev. 2 industry classification.[12] We apply full matching, meaning that one treated installation can be matched to many control installations and vice versa.[13] Thus, each matched pair consists either of one ETS installation matched to one or many control installations or of one non-ETS installation matched to one or many treated ones.[14] Using the same installation for more than one matched pair increases the bias, but also allows for a larger number of

[12] For example, within the sector ‘manufacture of fabricated metal products’, the three-digit nace classification distinguishes between ‘Manufacture of structural metal products’ (nace 251), ‘Manufacture of tanks, reservoirs and containers of metal’ (nace 252), ‘Manufacture of steam generators, except central heating hot water boilers’ (nace 253), ‘Manufacture of weapons and ammunition’ (nace 254). This list illustrates how narrowly defined these sectors are.

[13] We apply the command fullmatch from the optmatch package in R provided by Hansen and Fredrickson (2016), using a caliper of 0.3.

[14] Note that the second case is equivalent to matching with replacement.

matches which, in turn, translates into a larger sample size, thereby increasing efficiency. This is particularly important when the sample size is rather small as in the present analysis. Besides increasing the bias, another drawback of this procedure is that the final results might be driven by the emission path of some installations which have been used many times in the matching procedure. We address this issue in the robustness checks.

Table 3. Number of installations and observations in the matched sample by country

	# Installations		# Observations	
Country	ETS	non-ETS	ETS	non-ETS
France	169	96	1352	768
Netherlands	38	45	190	181
Norway	7	5	84	55
United Kingdom	26	22	305	219
Total	240	168	1931	1223

46. Our matched sample consists of 240 EU ETS-installations (out of 1,828 in the full sample) and 168 non-ETS installations (see Table 3). There are three major reasons for why a match was not always possible. First, we restrict our analysis to installations with at least one observation before and one observation after the launch of the ETS. Second, for some country-sector combinations we observed only EU ETS-installations, but no non-EU ETS installations or vice versa. Third, we applied a caliper so that installations whose distance in terms of pre-ETS emissions and emissions growth rate is too large cannot constitute a match. This prevents 'bad' matches where matched pairs are not sufficiently similar to each other.

47. It is important to note that, as part of the matching procedure, we give up a potentially much larger sample (basically all plants in the PRTRs) in favour of a much more focused comparison from which we are able to draw causal estimates of the impact of the EU ETS. In doing this, our estimates pertain by construction to smaller plants in the EU ETS (which have unregulated comparators) and not to regulated plants generally. In statistical terms, our estimates are internally valid but not necessarily externally so.

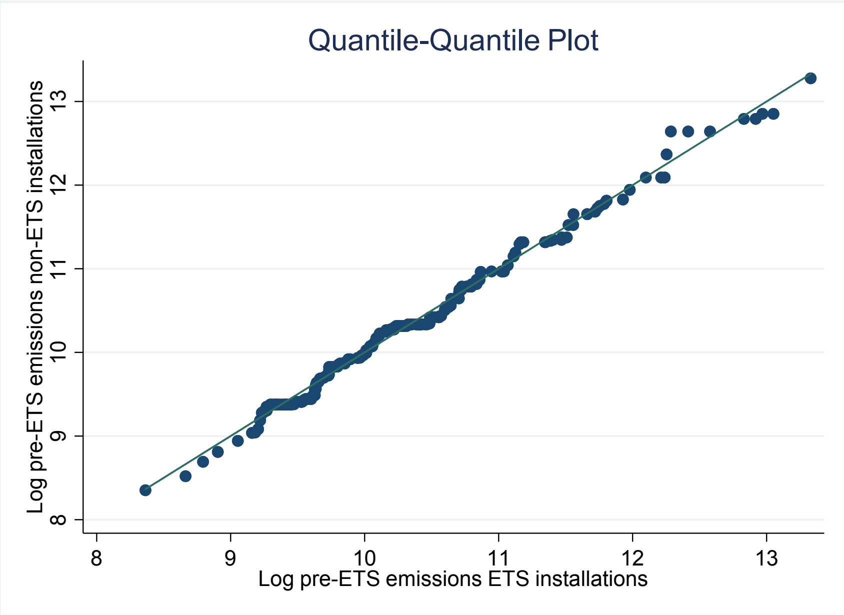
48. Table 4 Reports the matching quality in terms of the differences between ETS and non-ETS installations for the matching variables.

Table 4. Paired t-tests for ETS and non-ETS installations in matched sample

Variable	ETS	non-ETS	Difference	p-value
pre-ETS emissions	46966	46139	827	0.92
growth-rate	0.000	0.006	-0.006	0.97

49. While ETS installations have slightly higher pre-regulation emissions than non-ETS installations, the difference between treatment and control emissions is far from being statistically significantly different. Comparing the empirical distribution of ETS with non-ETS installations, Figure 7 indicates that there is no fundamental difference in terms of pre-ETS emissions between both sets of installations. Since installations do not differ in observable pre-ETS characteristics, these characteristics do not help to predict which installations would become regulated. In other words, the assignment of installations to the ETS after the matching appears to be quasi-random.

Figure 7. Comparison of matched ETS and non-ETS installations

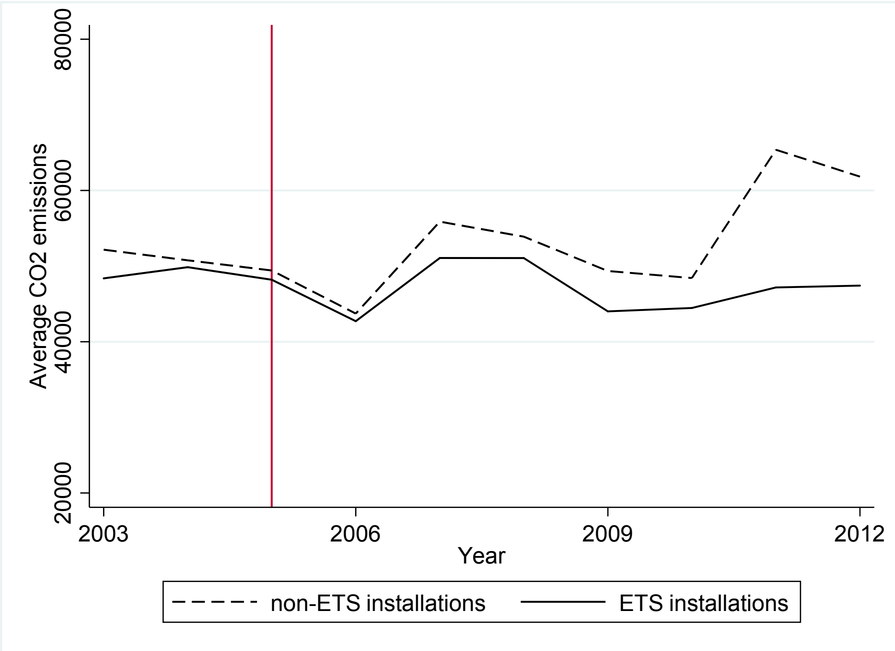


4.3. Results

50. Probably the most intuitive way to assess the impact of the EU ETS is by looking on the trend of emissions for matched ETS and non-ETS installations both before and after the implementation of the EU ETS as done in Figure 8. For this figure, we focus on the time interval for which we have data for all four countries, namely from 2003 onwards, the year in which French installations reported their emissions for the first time to the national PRTR. Two things are noteworthy from Figure 8. First, our matching has produced two very similar groups of installations before the implementation of the EU ETS since both groups have the same level of emissions and follow the same trend. Second, the trends tend to diverge after the implementation of the EU ETS in 2005, particularly after 2009, with ETS-installations having lower emissions than non-ETS installations.[15]

[15] Note that Norwegian installations became regulated by the EU ETS from 2008 onwards. However, these installations only constitute a very small part of our matched sample.

Figure 8. Emission trend before and after the EU ETS after matching (matched sample)



51. To shed more light on this pattern, we compare the emissions of ETS and non-ETS installations before and after the implementation of the EU ETS using regression analysis. Using a difference-in-differences approach, we estimate the percentage change of emissions that can be attributed to the EU ETS. To estimate the percentage change, one would normally take the logarithm of the emissions as the dependent variable and regress the independent variables thereon. However, our analysis is complicated by the fact that a substantial share of installations report zero emissions. Many French installations in our sample apparently switched from using fossil fuel towards the use of biofuels, implying the number of emissions originating from fossil fuel combustion to be zero. Since the log of zero is mathematically not defined, these observations cannot be used in the analysis anymore. Hence, we use Poisson regression instead of a log-linear regression following the approach of Silva and Tenreyro (Silva, J. and S. Tenreyro , 2006[35]).

52. The pollution registries which form our dataset do not contain any information on variables which are likely to have an impact on the emissions such as economic variables (revenue, profits, number of employees) or variables concerning the general economic environment (input prices, demand conditions). The matching procedure guaranteed that installations are similar with respect to the pre-ETS emissions, but they may still differ in terms of the factors above, which might affect regulated installations systematically different than unregulated ones. Hence, we expect much unobserved heterogeneity which may bias our estimates. We address this omitted variable bias problem by estimating a fixed-effects regression, thereby controlling for all time-invariant unobserved differences between treated and control installations.

53. Table 5 reports the estimated coefficients of the fixed effects estimator (column I and II) as well as for two other specifications (column III and IV). While the specification of column I does not include any control variables, column II adds year fixed effects. For columns III and IV, we estimate both a standard Poisson model as well as a zero-inflated Poisson model controlling for country, year and sector fixed effects, as well as for

installation size proxied by the level of pre-ETS emissions.[16] All specifications estimate a statistically significant treatment effect in the range of -0.10 to -0.14, meaning that the EU ETS led to a reduction of emissions by 10% to 14%. This corresponds to roughly 5 kt on average. Of course, this figure is only an average for the two trading phases and installations with different characteristics might be affected in a different way. Hence, in the following sub-sections we take a closer look at the evolution of the treatment effect over time and on the installation characteristics that drive this result.

Table 05. The causal impact of the EU ETS in the baseline scenario

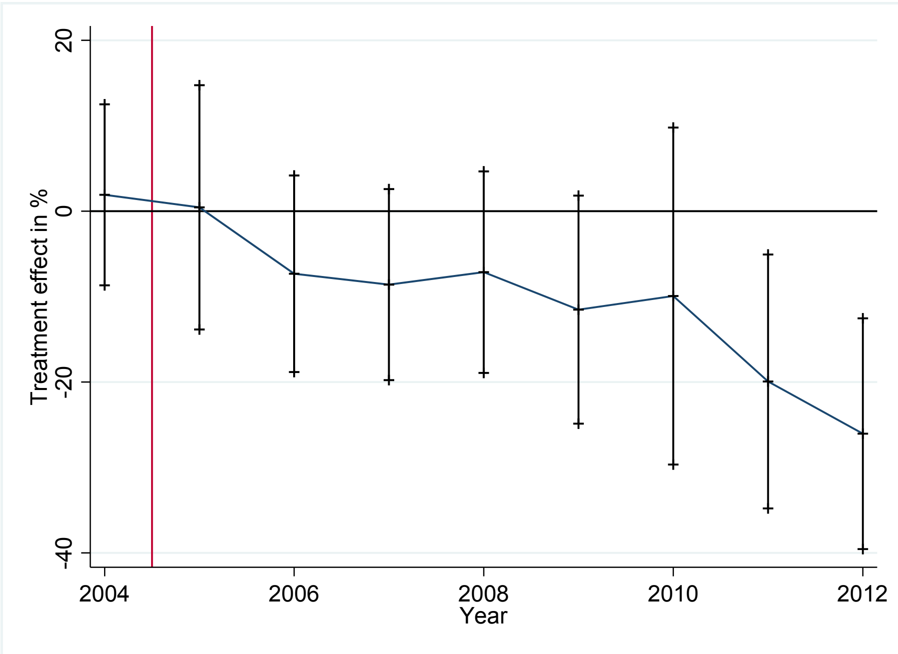
	(1)	(2)	(3)	(4)
Dependent Var.	CO2 emissions			
Estimation Method	Poisson			ZIP
Treatment Effect	-0.10*	-0.11*	-0.13**	-0.14**
	(0.06)	(0.06)	(0.06)	(0.06)
Installation FE	Yes	Yes	No	No
Year FE	No	Yes	Yes	Yes
Time-inv. Control Var.	No	No	Yes	Yes
# Observations	3153	3153	3153	3153
# Installations	407	407	407	407

4.3.1. Phases

54. The emissions trend in Figure 8 suggests that most of the emission reduction was observed in the second trading phase of the EU ETS. Estimating the treatment effect for each year, Figure 9 confirms this conjecture. While the treatment effect is negative from 2006 onwards, it is highest and statistically significant in the last two years of the second trading phase. Breaking down the estimate by phase, we observe a statistically insignificant emissions reduction of 6% for the first phase and a statistically significant reduction of 15% in the second phase. This is in line with the findings of Wagner et al. (Wagner, U. J., M. Muûls, R. Martin, and J. Colmer , 2014[25]) and Petrick and Wagner (Petrick, S. and U. J. Wagner, 2014[26]), who also report emissions reduction to be highest for the second phase, in which the permit price almost never fall below 10 euros per ton of CO2.

[16] Zero inflated Poisson models, first introduced by Lambert (Lambert, 1992[51]), account for an excess of zeros in the response variable. They consist of two components: The first component is governed by a binary distribution that generates structural zeros, i.e. if installations have exited the market or have entirely switched to the use of biofuels. The second component follows a standard poisson distribution which generates (emissions) counts.

Figure 9. Treatment effect by year

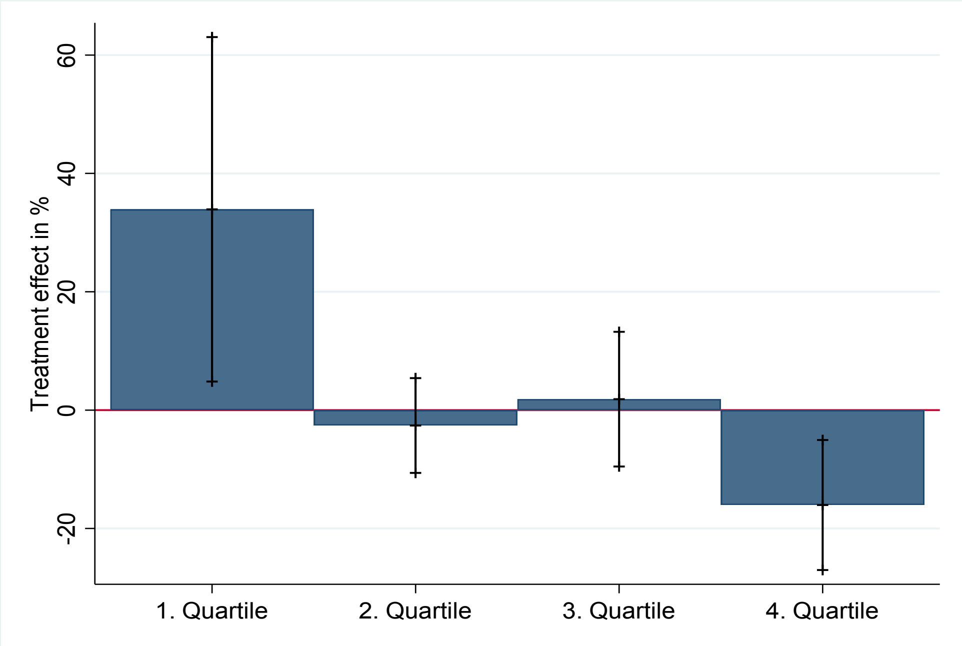


55. Because pollution control is capital intensive and typically involves high fixed costs, one might expect large firms to be more responsive to carbon pricing. For example, larger establishments may be able to spread fixed administrative costs induced by the new environmental regulation over a larger output, thus lowering the cost per unit of production. Therefore, we would expect smaller installations to abate relatively fewer emissions, thereby translating into a lower treatment effect.

56. Our dataset allows testing this hypothesis. Since we do not have data on installation size, we proxy the size by an installation's pre-ETS emissions. The larger these emissions, the higher should be the installation size. We split our matched sample into four quartiles and estimate the treatment effect for each quartile. Figure 10 shows the treatment effect along with the 95% confidence interval of the estimates.

57. The results show a clear relationship between installation size and the treatment effect. While the largest installations (4th quartile) significantly reduced their emissions compared to their control group, we do not find a statistically significant effect for the medium sized installations (2nd and 3rd quartile) and even find that the 25% smallest installations show a significantly positive treatment effect, meaning that the emissions of ETS-installations have not declined as much as those of the control group after the implementation of the EU ETS. Hence, the overall effect of the EU ETS on emissions reduction is predominantly driven by large installations in our matched sample.

Figure 10. Treatment effect by installation size



4.3.2. Impact by sector

58. Next, we investigate which sectors have experienced the largest EU ETS impact. Table 6 reports the treatment effect by sector.

Table 6. Effect of the EU ETS by sector

Dep. Var.: emissions	(1)	(2)	(3)	(4)	(5)	(6)
Sector	Treatment Effect				# Installations	# Observations
Manufacturing of food, beverages and tobacco	-0.06 (0.07)	-0.04 (0.06)	-0.05 (0.06)	-0.06 (0.06)	76	490
Manuf. of chemicals, pharma., rubber & plastic	-0.11 (0.08)	-0.13 (0.08)	-0.18** (0.08)	-0.19** (0.08)	142	1090
Manufacturing of non-metallic mineral products	-0.12* (0.07)	-0.12* (0.06)	-0.09 (0.06)	-0.09 (0.06)	52	378
Other manufacturing	-0.08 (0.06)	-0.06 (0.06)	-0.05 (0.05)	-0.06 (0.05)	67	621
Electricity, gas and steam	-0.11 (0.11)	-0.11 (0.10)	-0.11 (0.07)	-0.11 (0.07)	57	476
Estimation Method		Poisson		ZIP		
Installation FE	Yes	Yes	No	No		
Year FE	No	Yes	Yes	Yes		
Time-inv. Control Var.	No	No	Yes	Yes		

59. All sectors in Table 6 display a negative treatment effect between -6% and -19%. Because of the small sample size for individual sectors, the coefficient is not statistically significant except (depending on the specification) for the chemicals sector and the manufacturing of non-metallic mineral products. Our preferred specification (shown in column 2) suggests that the effect of the EU ETS may have been stronger in the chemicals, non-metallic mineral products and electricity sectors, but the estimated coefficients lack

the required precision to state that these effects are statistically greater than in other sectors. To conclude, there may have been heterogeneity of the impact across sectors, but all sectors seem to have experienced a decline in their carbon emissions.

4.3.3. Impact by country

60. Finally, we investigate the heterogeneity of the impact across the four countries. Table 7 reports the treatment effect by country. Not surprisingly, the impact in France is very close to our baseline impact reported above. This was expected since France constitutes the majority of our dataset. The impact in Norway is very large at around -40% but given the small number of observations in this country we caution against interpreting too much of these results. The point estimates are not statistically significant for the other two countries. Note that the coefficient is positive for the UK but very imprecisely estimated so that this result is compatible with a negative treatment effect – it is just impossible to tell from the data given the small sample size

Table 07. Effect of the EU ETS by country

Dep. Var.: emissions	(1)	(2)	(3)	(4)	(5)	(6)
Country	Treatment Effect				# Installations	# Observations
France	-0.13**	-0.12***	-0.13***	-0.13***	265	2120
	(0.05)	(0.04)	(0.04)	(0.04)		
Netherlands	-0.08	-0.16	-0.21	-0.22	82	370
	(0.12)	(0.14)	(0.15)	(0.15)		
Norway	-0.51***	-0.42***	-0.34**	-0.40***	12	139
	(0.14)	(0.14)	(0.15)	(0.14)		
United Kingdom	0.02	0.10	0.14	0.14	48	524
	(0.11)	(0.10)	(0.11)	(0.11)		
Estimation Method		Poisson		ZIP		
Installation FE	Yes	Yes	No	No		
Year FE	No	Yes	Yes	Yes		
Time-inv.Control Var.	No	No	Yes	Yes		

4.3.4. Allocation of free emission allowances

61. There is an ongoing debate around the neutrality of the allocation mechanism of emission trading schemes in general (Hahn, R. and R. Stavins , 2011[36]) and the EU ETS in particular (De Vivo, N. and G. Marin, 2017[37]; Zaklan, 2016[38]). According to the Coase Theorem (Coase, 1960[39]), the level of emissions of each participant in a trading scheme does not depend on the assignment of property rights. Applying this theorem to the EU ETS means that we should expect the same distribution of abatement choices independently from the allocation mechanism applied. However, this 'independence property' might not hold in a real-world trading scheme, because of transaction costs (Stavins, 1995[40]), imperfect competition (Hahn, 1984[41]), and behavioural anomalies such as an endowment effect (Kahneman, D., J. Knetsch and R. Thaler, 1990[42]).

62. Our dataset allows us to examine whether the magnitude of the treatment effect is affected by the generosity of the allocation of free allowances. As a proxy for generosity, we use the ratio between the average annual amount of freely allocated certificates in the first two phases and the last observed pre-ETS emission value. Using pre-ETS emissions instead of actual emissions for the construction of this measure guarantees that the ratio is

not confounded by emissions abatement due to the EU ETS.[17] The higher the ratio, the more generous is the allocation of free allowances. A ratio equal to one indicates that, on average across the two phases, installations get entirely compensated by free certificates.[18] We then interact the ratio with the treatment effect variable and estimate our baseline model, including installation and year fixed effects. The coefficient of the interaction term is positive and statistically significant at the 1% level, indicating that the reduction of emissions induced by the EU ETS is a function of the allocation of free allowances. Figure 11 illustrates this finding by plotting the size of the treatment effect as a function of the ratio of free allowances over pre-ETS emissions.

63. Figure 11 indicates a clear positive relationship between the ratio and the magnitude of the treatment effect, meaning that a more generous allocation of free allowances translates into a lower treatment effect in absolute terms. The average ratio in our sample is 1.05, which translates into the baseline treatment effect of around -10%. However, this finding implies that, had all installations received only half of their pre-ETS emissions, then the impact of the EU ETS on emissions reduction would have been much larger at around -25%. Interestingly, we also observe that the impact of the EU ETS on emissions ceases to be statistically different from zero for all values of the allowances-to-past emissions ratio above 1. On average, over-allocated installations have not reduced emissions, a finding which goes against the independence property of free allowances. This finding suggests that the impact of the EU ETS on CO2 emissions should increase in the years to come, independently of the total emissions cap, as fewer and fewer emissions allowances are allocated for free.

[17] Suppose there are two identical installations receiving the same number of freely allocated allowances and having the same level or pre-ETS emissions as well as the same emission trend under business as usual. Suppose further that one installation abates some emissions whereas the other does not. If we were to base our measure of generosity on the ratio between free allowances and actual emissions, then the abating installation would have a higher ratio than the non-abating one, indicating a more generous allocation towards the installation that has shown some abatement effort. To avoid this misinterpretation, we base the measure of generosity on pre-ETS emissions

[18] We set the value of the ratio to one for all installations in the control group.

Figure 11. Relationship between allocation of free allowances and treatment effect

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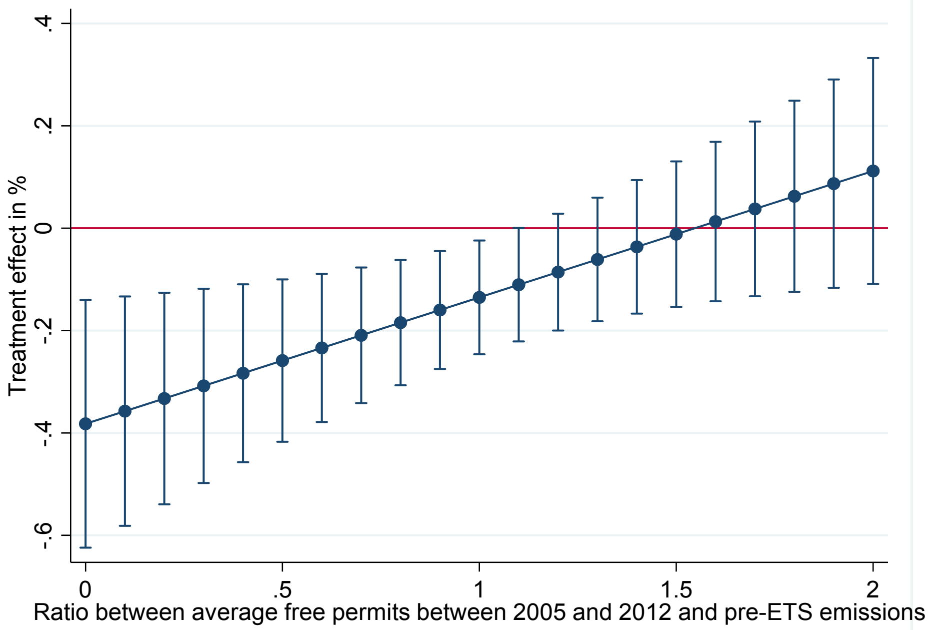

4.4. Sensitivity Analysis

64. We ran various robustness checks and the main ones are reported in Table 8. Overall, our results are fairly stable and the estimated treatment effects range between 6% and 16%.

65. Results according to installation size suggest that most of the emission reduction is driven by large installations. To address this point, we excluded the 1% largest installations based on their pre-ETS emissions. The point estimate remains statistically significant, though its magnitude becomes smaller. Another concern is that the results might be driven by outliers which have a huge impact on the size of the point estimates. This is particularly relevant in our case because we are matching with replacement, meaning that the weight of an unregulated installation may be high when it serves as match for several regulated installations. We address this concern by removing installations with the 1% largest impact on the point estimate in each direction.[19] The treatment effect drops to -0.06, but remains statistically significant at the 10% level. A third concern is that our estimates are driven by installations that have switched from combusting fossil fuels to using biofuels. To address this we take the reported total CO2 emissions without subtracting the emissions stemming from biofuels, and find the treatment effect to remain at -0.11. This shows that the results are not driven purely by a switch toward biomass. Finally, we restrict the estimation to a

[19] Technically, we estimate our specification several times, each time excluding one installation from the matched sample. The impact of each installation on the treatment effect is then the difference between the point estimate of the full sample and the point estimate of the restricted sample that excludes this installation.

balanced panel. While the point estimate shows the same magnitude, it is not statistically significant anymore because the number of installations more than halved.

66. Next, in some cases regulated installations do not report emissions to the PRTR but do report emissions to the EUTL. In the baseline results only PRTR emissions are used, but as a robustness check we exploit this additional information by substituting the emission value from the EUTL whenever it is missing in the PRTR. The estimated emissions reduction increases from 11% to 16%. The reason for the increase is that most substituted emissions are values below the reporting threshold from installations that apparently managed to reduce their emissions post-ETS under the reporting threshold. Substituting these values from the EUTL adds many small values for the regulated groups, thereby strengthening the treatment effect. In another robustness check, we substitute the values from the EUTL if and only if the matched control installation has a non-missing emission value in that year.[20] The point estimate increases to 12% and this increase is due to the same reason as above. The PRTR data also enables us to infer some information regarding non-reported emissions value. CO2 emissions reports might be missing because the installation might have forgotten to submit the CO2 emissions, because the emissions value is below the reporting threshold or because the installation does not operate anymore. We can exploit PRTR information to detect the last case by looking at all other reported substances of each installation. If an installation stopped to report any substance to the PRTR, then it is likely to have exited the market, in which case we assign an emissions value of zero. Doing this increases the emissions reduction slightly to 12%, and the coefficient remains statistically significant.

67. Even if our estimate of the impact of the EU ETS on carbon emissions reductions appears fairly robust within our matched sample, a more serious challenge to our conclusion is the small number of observations which might prevent us from extrapolating from this set of installations to all EU ETS installations in the four countries (and, beyond, to all EU ETS installations across Europe). In order to address this issue, we start by relaxing our matching procedure and matching exactly on the 2-digit instead of on the 3-digit NACE code. Although one would naturally want to match firms using the finest possible sector definition, we face a difficult trade-off. First, some sectors were almost fully regulated by the EU ETS, as explained in Section 2. Therefore, matching at the NACE 3-digit sector, although appealing because we can in theory better control for sector-specific trends, leaves us with fewer matches than matching at a higher level. Matching at NACE 2-digit level therefore allows to substantially increase our sample size, but at a potential cost in terms of accuracy. Secondly, matching firms using the finest possible sector definition makes it theoretically possible that we match close competitors with each other. Imagine for example that there are two plants in a country that both produce the exact same output (e.g., the same type of cement). Once the EU ETS regulation is passed, cement produced by the EU ETS plant should become more expensive, inducing customers to then favour cement from the non-ETS plant. This implies that the policy has also affected the non-ETS plant. Matching at a higher level reduces the likelihood that two close competitors are matched with each other, but at the cost that the two installations might not face the same demand conditions and thus follow parallel trends.

68. Matching at NACE 2-digit level increases the matched sample by almost 300 installations while potentially reducing the matching quality (because installations can now

[20] If a treated installation is matched to many controls, then we substitute the value from the EUTL if and only if at least half of the matched control installations report a non-missing emissions value.

be matched to installations operating in quite different sectors) but reducing the probability of matching competitors together. For example, within the non-metallic minerals sector an installation manufacturing glass can now be matched to an installation that produces cement. Applying this matching procedure reduces the point estimate to -0.07, but it remains statistically significant.

69. We also check for a less robust matching procedure by allowing matches between installations that have a higher distance in terms of emissions and emissions growth rate, but which are matched exactly on NACE 3-digit and country. Doing this increases the sample size to 855 installations, but comes at the cost that regulated and unregulated installations are not so similar anymore. The treatment effect of this DiD estimator remains at -0.07, but fails to be statistically significant due to the larger heterogeneity of the matched sample.

70. In sum, our estimate of the impact of the EU ETS on carbon emissions reductions appears fairly robust and is in the range of -6% to -12%. However, it remains that our results cannot easily be generalized to the whole EU ETS beyond the four countries for which data could be collected.

Table 8. Robustness checks

Robustness check	EU ETS effect	# Installations	# Observations
Remove 1% largest installations	-0.08**	403	3124
	(0.04)		
Remove most influential installations	-0.05*	393	3040
	(0.03)		
Not subtract emissions from biofuels	-0.11*	407	3118
	(0.06)		
Remove unbalanced installations	-0.11	185	1818
	(0.07)		
Add verified emissions from EUTL	-0.16**	407	3490
	(0.07)		
only if matched control is non-missing	-0.12*	407	3262
	(0.06)		
Add zero emissions for exiting installations	-0.12**	407	3288
	(0.06)		
Match on NACE 2-digit code	-0.07*	673	5393
	(0.04)		
Less exact matching	-0.07	855	8778
	(0.05)		

5. The causal impact of the EU ETS on economic performance

71. Having established that the EU ETS has reduced carbon emissions by 6% to 12%, we now ask whether this impact on environmental performance also affected the economic performance of regulated companies. The analysis is based on the same matching methodology but the main difference is that the economic performance data is at the level of companies and not installations. The working dataset is also much larger, as we are not constrained by the reporting thresholds of national pollution registries. Therefore, the firm analysis can cover all countries covered by the EU ETS rather than a subset, and we can apply nearest-neighbor matching, thereby reducing potential bias to a minimum.

5.1. Data and descriptive statistics

5.1.1. Linking EU ETS firms with financial data

72. The first step of the data construction consists in identifying companies in Europe that are regulated by the EU ETS, i.e. firms that operate at least one EU ETS-regulated installation. For eight of the countries in our sample, the company registration numbers of the installation operators were obtained directly, either from national emissions trading registries or from the European Union Transactions Log (EUTL), the EU body to which national registries report. For the remaining 23 countries in our data set that participated in the 2005 launch of the EU ETS, a combination of exact and approximate text matching methods were used to establish a link between firm data and regulatory data. This was complemented by further manual searches, and extensive manual double-checking. We also cross-check the quality of our matching with the European University Institute's Ownership Links and Enhanced EUTL Dataset Project, which provides a publicly available link between EU ETS accounts and parent companies.[21]

73. Our linking between the EUTL and company registration numbers leaves us with over 8,200 firms operating more than 14,000 installations regulated under the EU ETS, together accounting for over 99% of EU ETS-wide emissions. We then merge EU ETS firms with Bureau Van Dijk's Orbis database using the company registration numbers. From Orbis, we extract financial information on both EU ETS and non-EU ETS firms on turnover, fixed assets, profits and employment, as well as companies' core activity code at the NACE 4-digit level.

5.1.2. Data cleaning

74. We apply a cleaning procedure to the dataset before moving on to the analysis. We exclude firms with missing data before 2005 or missing NACE activity code, and firms operating in sector-country combinations with only EU ETS firms or only non-EU ETS firms. We also carefully check for absurd outlying observations that obviously correspond to errors in the data collection (for example, a company that has 300 employees on one year, 30 the next year and again 300 the year after) and replace those absurd values with missing values. Finally, the financial data set allows us to identify majority ownership. Using this information, we excluded non-EU ETS firms that were owner, sister company, or subsidiary to an EU ETS firm. This reduces the chance of matching two potentially dependent observations.

5.1.3. Final dataset

75. After implementing this cleaning procedure, we are left with 448,489 firms, of which 4,285 are EU ETS firms. Table 9 and Table 10 respectively show the distribution of EU ETS and non-EU ETS firms across countries and across sectors.

[21] http://fsr.eui.eu/climate/ownership-links-enhanced-eutl-dataset-project/

Table 9. Number of EU ETS and non-EU ETS companies by country before matching

Country	Number of EU ETS firms	Number of non-EU ETS firms
Austria	40	555
Belgium	182	2842
Bulgaria	79	2389
Czech Republic	187	6605
Denmark	59	3485
Estonia	22	230
Finland	114	2270
France	348	64808
Germany	437	12029
Greece	77	1990
Hungary	31	357
Iceland	1	2
Ireland	2	2
Italy	510	98825
Latvia	38	735
Lithuania	40	260
Luxembourg	2	2
Netherlands	62	4432
Norway	58	8629
Poland	453	6500
Portugal	19	36
Romania	168	34335
Slovakia	66	675
Slovenia	59	783
Spain	689	157101
Sweden	205	10470
United Kingdom	337	23857

Table 10. Number of EU ETS and non-EU ETS companies by sector before matching

Sector	Number of EU ETS firms	Number of non-EU ETS firms
Electricity	410	2446
Basic Metals	211	3125
Cement & Lime	123	350
Ceramics	460	1445
Chemicals	288	6190
Glass	156	1596
Paper	413	3881
Other Sectors	2224	425171

5.2. Matching

76. In order to analyse the impact of the EU ETS on regulated companies, we construct a control group of firms similar to EU ETS firms prior to the introduction of the policy in 2005. This makes it more difficult to explain away any difference in outcomes by factors other than the EU ETS. Ideally one would like to match each EU ETS firm with one or more non-EU ETS firms with similar resources available and facing similar demand conditions, regulations (other than the EU ETS), input prices, etc. Because of how the EU

ETS was designed and implemented, this procedure is theoretically possible. As explained in Section 2, regulatory status is determined by applying inclusion criteria to installations, not firms. For instance, installations for which the main activity is "combustion of fuels" are included only if their annual thermal input exceeds a threshold of 20 MW. For steel plants, the relevant inclusion criterion is instead that installations have a production capacity exceeding 2.5 tonnes per hour. Installations manufacturing glass and glass fibre are included only if their melting capacity exceeds 20 tonnes per day. This configuration means that EU ETS and non-EU ETS firms can, in principle, be identical in all respects relevant to their economic performance, except for the size of a single installation. This allows us, in theory at least, to form groups of similar EU ETS and non-EU ETS firms. In practice, we restrict ourselves to more closely matched firms, excluding a number of EU ETS companies for which no good match can be found (for example, we cannot find an electricity production company in France which is of a similar size as EDF, so EDF cannot be matched to a good control firm). What is lost in sample size, however, is regained in terms of accuracy and robustness (Dehejia, R. and Wahba, S., 1999[43])

77. Our data set contains information on the country and economic sector in which firms operate as well as other firm-level information such as revenue, fixed assets, employment and profit. Using this data, we have tried to assign to each of the 4,285 EU ETS firms a similar but unregulated firm. We match exactly on country and economic sector (defined at NACE 3-digit level), and use data from the pre-regulation period 2002-2004 to assign each EU ETS firm to the closest possible firms in terms of revenue, fixed assets, number of employees and EBIT (earning before interests and taxes, i.e. operating profit or loss). Though, this has not always been possible, because even though EU ETS regulations were applied at the installation level rather than directly to the firm, one might expect two very similar firms to receive the same regulatory treatment more than occasionally. Different regulatory fates are possible if, say, an EU ETS firm operates an installation just large enough to be covered by EU ETS regulations, while the matched control operates one or more installations just below the threshold. But even though we have a very large pool of firms to start with, sometimes there will be no such comparators available within the same country and sector. Therefore, the final matched sample contains 1,787 ETS firms and 1,280 non-ETS firms. There is one matched control firm for every ETS firm. Matching is applied with replacement which implies that sometimes one non-ETS firm serves as a match for several ETS firms. This explains why the control sample is smaller than the ETS sample. Both one-to-one matching and matching with replacement minimize bias at the expense of the efficiency of the estimator. The efficiency of the estimator is of lesser concern in this section, since we have a very large sample to start with.[22]

78. Restricting the pool of potential matches to those which operate in the same countries and economic sectors as the EU ETS firms means that they are likely exposed to much the same business and regulatory environment, input prices (in particular energy prices), country and sector specific shocks and trends. The firms are also matched to have similar pre-2005 turnover, number of employees, assets and profit, since their available resources (and capacity for investment and research and development activities) are likely important determinants of a firm's response to the EU ETS. Table 11 shows that, after

[22] The emissions analysis in Section 4 was heavily constrained by the sample size, which is why we implemented full matching, allowing us to recover more pairs of EU ETS and non-EU ETS installations at the cost of accuracy. The sample is much larger in this section of the study, so we can proceed with one-to-one matching in order to minimize bias.

matching, the two groups of firms are statistically indistinguishable from each other: we cannot reject at conventional significance levels that the two groups have the same mean for turnover, number of employees, assets and profit. We find that EU ETS are slightly larger (but not statistically significantly so) than non-EU ETS matched firms on all observable characteristics used in the matching procedure (revenue, fixed assets, employees and profit). This is perhaps not surprising, since among firms operating one installation only, EU ETS firms are bound to be larger, by definition, than non-EU ETS firms. However, our matching procedure has made both groups very similar on all observable characteristics.

Table 011. Paired t-tests for matched EU ETS and non-EU ETS firms

Matching variable	Mean of EU ETS firms	Mean of non-EU ETS firms	Difference in means	p-value for H0: Difference in means = 0
Revenue (th. EUR)	78786.89	76813.64	1973.25	0.21
Fixed assets (th. EUR)	50851.09	49737.29	1113.8	0.37
Number of employees	286.61	285	1.61	0.72
EBIT (th. EUR)	4570.81	4310.59	260.22	0.32
Placebo test: variable not used in matching				
Firm age	37.78	36.95	-0.84	0.25

79. The primary challenge for any matching study is to justify the assumption that firms that appear similar are similar in unmeasured dimensions as well—often called selection on observables. In a randomized experiment, one can rely on the law of large numbers to achieve similarity between a treated and control group on both observed and unobserved characteristics. Matching, on the other hand, achieves an observed similarity by construction, so similarity on matched characteristics cannot be read as evidence that the treated and control firms are also similar on unobserved characteristics. A simple test of whether matching has achieved balance on unobserved variables is to look at a variable that was not used to construct the matches. We have one such variable in our data set: the age of firms. As the last line in Table 11 shows, the average age of the EU ETS and non–EU ETS firms is very similar, and we cannot reject the hypothesis that they are materially the same. In other words, even though the age of firms was not used to build the matched sample, it nevertheless appears equal among EU ETS and non-EU ETS firms, suggesting that both sets of firms are similar in other dimensions than the variables used in the matching procedure. We can therefore have some confidence that matching has indeed recovered the central identifying condition of a randomized experiment.

80. Figure 12 compares the empirical distributions of EU ETS and non-EU ETS firms in our matched sample on the key variables used to construct the match. If both sets of firms have the same probability distribution, the dots all appear on the 45° line. As can be seen from Figure 12, the empirical distributions of EU ETS and non-EU ETS firms are extremely close to the 45° line, suggesting that the matching has done a good job at creating similar groups of firms.

Figure 12. Comparison of matched ETS and non-ETS firms

Note: Panel (a) displays the empirical quantile-quantile (e-QQ) plot for revenue on a logarithmic scale in 2002-2004, the 3 years before the EU ETS. Each dot gives the value for nth largest revenue of ETS firms and the nth largest revenue of non-EU ETS firms, shown on logarithmic scales. If both sets of firms have the same probability distribution, the dots are close to the 45° line. Panels (b), (c) and (d) show the e-QQ plots for the number of employees, fixed assets and profit (EBIT). Panels (b) and (c) are shown on logarithmic scales, but not panel (d), as profits can be negative.

81. In order to avoid any potential bias created by pre-treatment differences, our matching procedure is combined with a difference-in-differences approach. This means that we do not compare revenue between ETS and matched non-ETS companies, but the change in revenue between 2004 (before the introduction of the EU ETS) and the 2005-2014 period. Therefore, the identification strategy is based on the assumption that conditional on the matching variables (sector, country, revenue, fixed assets, employment, profits) the outcome variables of ETS firms and non-ETS firms would have followed a parallel trend in the absence of the EU ETS.

5.3. Baseline results

82. The most transparent and intuitive way to view the results is with the aid of a simple graph plotting the revenue, assets, employment and profit of matched EU ETS and non-EU ETS firms both before and after the EU ETS came into effect (see Figure 13). In all four

cases, the EU ETS and non-ETS firms follow parallel trends before the introduction of the EU ETS (up to 2004), and statistical tests confirm this visual observation.[23]

Figure 013. Revenue, employment, fixed assets and profits for matched ETS firms and non-ETS firms, 2002-2014

Note: Graphical representation of the difference-in-difference approach. The effect of the EU ETS is assessed statistically in the regressions by comparing the different trends between matched ETS firms and non-ETS firms.

83. We observe that the trends remain roughly parallel for ETS firms and non-ETS firms for all outcome variables. Comparing the two groups of firms, however, the gap

[23] The formal test is to interact the treatment variable (ETS) with time dummies in regressions in which the dependent variable is the outcome of interest (revenue, fixed assets, employment or profits) for firm i at year t and we control for time and firm fixed effects. In practice, we include the interactions of the time dummies and the treatment indicator for the first two pre-treatment periods and you leave out the one interaction for the last pre-treatment period (to avoid collinearity), so that all the other interactions are expressed relative to the omitted period which serves as the baseline. We find that the coefficients on the interactions of the time dummies and the treatment indicator for the first two pre-treatment periods for all outcomes, suggesting that the outcome trends between treatment and control group are statistically indistinguishable

between EU ETS and non-EU ETS firms seems to widen for revenue, fixed assets and the number of employees. There is almost no difference in terms of profits in the period following the EU ETS introduction. We now assess whether this apparent widening gap is significant from a statistical point of view.

84. In order to determine the causal impact of the EU ETS on regulated companies, we run regressions of the form $Y_{it} = \alpha ETS_i + \beta post + \gamma ETS_i * post + \delta_i + \theta_t + \varepsilon_{it}$, where Y_{it} is either turnover, assets, number of employees, profit or return on assets (profit over assets); ETS_i is a dummy variable equal to one for firms that became regulated by the EU ETS in 2005 or later; $post$ is a dummy variable equal to one for the post-treatment period (2005 for most firms) and $ETS_i * post$ is the interaction between these two variables. γ is the main coefficient of interest. To account for potential pre-treatment differences between ETS and non-ETS firms before the implementation of the EU ETS, the regressions include firm fixed effects denoted by δ_i. Year dummies denoted by θ_t capture any shock that is common to all firms, such as macroeconomic fluctuations like the financial crisis. The regressions are run in logs or in levels and we use OLS or Poisson models depending on the nature of the dependent variable. In addition, we run a probit regression where the dependent variable Y_{it} is a dummy variable equal to one for any year $T \geq t$ if firm i closed down in year t. This allows us to estimate the impact of joining the EU ETS on the probability of firm closure.

Table 12. The effect of the EU ETS on revenue, employment, assets and profits

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.1671***	0.0811***	0.0234	283.6478	0.0002	0.2374
	(0.0256)	(0.0225)	(0.0214)	(211.2466)	(0.0049)	(0.2285)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	42834	41666	23958
# firms	3766	3766	3765	3758	3766	2662

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level. The causal effect of the EU ETS corresponds to the coefficient of ETS*Post. All regressions except column (6) include firm fixed effects that control for any remaining differences between EU ETS and non-EU ETS companies after matching. It is computationally infeasible to include firm fixed effects in the probit regression and so this one includes country and sector (defined at the NACE3 level) fixed effects instead.

85. Our main results can be found in Table 12. The causal effect of the ETS is captured by the interaction dummy $ETS_i * post$. We find that ETS firms experienced a higher increase in revenue and in fixed assets compared to non-ETS control firms, and this difference is statistically significant at the 1% level. In terms of magnitude, we find that ETS-firm's revenues were 16% higher on average during the ETS period compared to what they would have been had they not been regulated. ETS firms also increased their fixed assets by around 8% compared to the counterfactual scenario of no EU ETS. A natural explanation for this impact on fixed assets is that regulated companies reacted to the introduction of the EU ETS by adopting costly emissions-reduction technologies. As we have seen in Section 2, the price of carbon allowances on the European market has been unexpectedly low since 2005. While this could have reduced incentives to invest in

emissions-reduction technologies, it is fundamentally expectations over future carbon prices which drive technology adoption. Since the overall cap of emissions under the EU ETS is known until 2030, and is planned to decrease every year, companies subject to the regulation should anticipate the future tightening of the cap and the implied increase in future carbon prices by investing today in carbon-saving technologies. In fact, it has been demonstrated elsewhere that EU ETS-regulated firms reacted to the introduction of the policy by filing 30% more patents in low-carbon technologies compared to a counterfactual scenario (Calel, R. and Dechezleprêtre, A., 2016[7]).

86. We also find that EU ETS firms increased employment and profits compared to the non-ETS control firms, but this difference is not statistically significantly different from 0. Returns on assets (i.e. profits scaled by assets) also did not experience any statistically significant change compared to the control group. Finally, EU ETS firms were not more likely to close compared to unregulated firms. The coefficient is positive but not statistically different from zero.

5.4. Sensitivity analysis

87. We explored the robustness of our findings in a number of ways and report the main sensitivity checks we conducted in this section.

5.4.1. Better controlling for country- and sector-specific trends

88. In the baseline results, revenue, assets and profits are expressed in nominal values. However, there could be country- and sector-specific inflation which could partly affect the magnitude of our point estimates. Similarly, although the matching procedure is designed to control for country- and sector-specific trends, since each control firm is selected from the pool of firms operating in the exact same country and sector as the treated firm, the final distribution of matched firms across countries and sectors could affect our point estimates if macroeconomic trends differ across countries and sectors. To account for these possible threats to our analysis, in Table 13 the regressions include country-by-year and sector-by-year time dummies.

89. As shown in Table 13, including these additional control variables actually leads to larger point estimates. We find that the EU ETS led firms to increase revenues by 18% and assets by 10%. Interestingly, the coefficients for the number of employees and for profit are not statistically different from zero (although only at the 10% level), suggesting that the EU ETS may have also had a positive impact on firms' employment (+3%) and profits (+ 370,000 euros on average). We rule out, however, that not controlling for country- and sector-specific trends in the baseline regressions would have led us to overestimate the treatment effect of the EU ETS.

Table 13. Controlling for country- and sector-specific trends

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.1880***	0.1022***	0.0348*	370.4282*	0.0004	0.2373
	(0.0245)	(0.0224)	(0.0190)	(212.8643)	(0.0049)	(0.2285)
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector-year FE	Yes	Yes	Yes	Yes	Yes	Yes
# obs.	42742	42640	40117	42834	41666	23958
# firms	3766	3766	3765	3758	3766	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.4.2. Keeping only firms observed throughout the whole sample period

90. The baseline results have been obtained by using all possible observations, irrespective of whether some of the data might be missing for some years (for example, a firm might have missing data for the number of employees in a specific year). However, our data suggests that the number of missing values is on average twice as high for non-EU ETS than for EU ETS firms. This could signal that EU ETS firms have better institutional capacity or that they differ from non-EU ETS firms in some unobserved but systematic way. To deal with this issue, we run two tests: first, we apply a procedure to replace any observed value with a missing if that value is missing for the matched firm within each pair. For example, if an EU ETS firm has non-missing employee data in 2010 but its control has missing employee data in that year, we replace the 2010 value for EU ETS firms with a missing. Secondly, we restrict the set of firms to those that are observed throughout the whole sample period for all our variables of interest. This should remove any remaining systematic difference between the treated and the control group.

91. Results are presented in Table 14 and Table 15. Implementing the "pairwise missing replacement" procedure reduces the number of observations by about 10% but leaves the results virtually unchanged. Restricting the set of firms to those that are observed throughout the whole sample period for all our variables of interest further reduces the sample to around 60% of firms in the baseline sample. Here, the impact of the EU ETS on revenues goes down at around 11% compared to 16% in the baseline sample, which could be viewed as a conservative estimate of the true treatment effect. Results on employment and closure are left unchanged, but we find a positive treatment effect of the EU ETS on profits (but not on return on assets), which could be linked with windfall profits. We explore this possibility further in the next section.

Table 14. Pairwise missing replacement procedure

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.1565***	0.0750***	0.0039	227.9502	0.0041	0.3305
	(0.0255)	(0.0226)	(0.0231)	(214.8222)	(0.0050)	(0.2022)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	38188	38251	34777	38533	37252	30382
# firms	3766	3766	3746	3761	3766	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

Table 15. Keeping only firms observed throughout the sample period

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.1162***	0.0731***	0.0198	458.1339*	-0.0009	0.1548
	(0.0281)	(0.0269)	(0.0265)	(272.1462)	(0.0059)	(0.2532)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	28581	28601	26952	28830	28049	14319
# firms	2278	2278	2277	2270	2278	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.4.3. Matching at NACE 2-digit or 4-digit level

92. The baseline results have been obtained by matching exactly on the EU ETS firms' core sector of activity as reported in Orbis at the NACE 3-digit level. Although one would ideally match firms using the finest possible sector definition, we face a trade-off here as some sectors were almost fully regulated by the EU ETS, as explained in Section 2. Therefore, matching at the NACE 4-digit sector, although appealing because we can then better control for sector-specific trends, leaves us with fewer matches than matching at a higher level. Symmetrically, matching at NACE 2-digit level allows to substantially increase our sample size, but at a potential cost in terms of accuracy.

93. Therefore, we ran the same analysis as above but matching companies at the NACE 4-digit level or the NACE 2-digit level. Matching at NACE 2-digit leaves us with 4448 firms (up from 3766) while matching at NACE 4-digit reduces this to 2984 firms. Matching at NACE 4-digit leaves the results virtually unchanged (Table 16). However, matching at NACE 2-digit substantially reduces the impact on revenue at +7.5% (Table 17). We find a marginally significant positive impact on profits, and the EU ETS is now estimated to increase the probability of firm closure by approximately 1%, but since probit regressions cannot include firm fixed effects we caution against inferring too much from this marginally statistically significant result. At any rate, these robustness checks provide reasonable bounds for the treatment effect.

Table 016. Matching at NACE 4-digit level

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.1794***	0.0732***	-0.0017	316.6415	-0.0003	0.2106
	(0.0291)	(0.0253)	(0.0281)	(215.9609)	(0.0053)	(0.2538)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	33582	33533	31655	33829	32787	18342
# firms	2984	2984	2983	2977	2984	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

Table 017. Matching at NACE 2-digit level

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Post	0.0750***	0.0655***	0.0072	397.7359*	-0.0001	0.2396*
	(0.0222)	(0.0214)	(0.0200)	(214.0453)	(0.0046)	(0.1403)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	50686	50620	47754	50767	49470	29376
# firms	4448	4448	4446	4445	4448	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.4.4. Conclusion from the sensitivity analysis

94. To conclude on these sensitivity checks, we can rule out the idea that the EU ETS had any negative effect on the economic performance of regulated firms. In fact, we find that EU ETS firms reacted by increasing fixed assets and revenues, although we cannot determine whether this increase in revenues is due to an increase in the volume of sales or in prices. The most robust and stable impact is on fixed assets, which are estimated to increase by 6% to 10% across specifications, consistent with the idea that firms react to the introduction of the EU ETS by investing to modernize their production process. The positive impact on revenue is extremely robust, but the magnitude is less precise: the EU ETS is estimated to have increased revenue by 7% to 18% depending on the specification. The EU ETS has had no statistically significant impact on employment on average, and possibly a small positive impact on operating profit. In the next section these results are explored further. In particular, the heterogeneity of the impact is analyzed across time, sectors and type of firms.

5.5. Exploring heterogeneity

5.5.1. Effect of the EU ETS by phase

95. We start by exploring the impact of the EU ETS across its three phases (2005-2007; 2008-2012; 2013-2014). Results are shown in Table 18. We find a positive and statistically significant impact of the EU ETS on revenue and assets in all three phases. However, the impact is much larger in Phases 2 and 3 than in Phase 1. This might be surprising, given that the allocation of free allowances was more generous in Phase 1 than in Phases 2 and 3. However, it is important to keep in mind that the "operational revenues" variable we use does not include potential financial revenues from selling allowances on the market. It could, however, be at least partly influenced by cost pass-through of carbon prices on product prices. We also find that Phase 2 may have led to an increase in employment and profits, but the effect is only statistically significant at the 10% level. Finally, it is interesting to note that the positive effect on return on assets found in Phase 1 may have reversed in Phase 3. This is compatible with higher abatement costs in the more recent period, as cheap emission reduction options become less available.

Table 18. Effects by EU ETS phase

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Phase1	0.0999***	0.0387**	-0.0150	449.6347	0.0118*	-0.1089
	(0.0188)	(0.0173)	(0.0165)	(304.2823)	(0.0064)	(0.2772)
ETS* Phase2	0.2067***	0.1028***	0.0486*	601.9555*	-0.0018	0.1376
	(0.0315)	(0.0275)	(0.0282)	(323.7571)	(0.0073)	(0.2258)
ETS* Phase3	0.1972***	0.1102***	0.0478	127.6297	-0.0212**	0.3246
	(0.0528)	(0.0400)	(0.0451)	(406.7781)	(0.0090)	(0.2228)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	28830	28049	33894
# firms	3766	3766	3765	2270	2278	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.5.2. Effect of the EU ETS by company size

96. We also explore the heterogeneity of the effect by firm size, using the definition of what constitutes a Small, Medium-sized and Large company according to the European Commission. Results are reported in Table 19. We find that the impact on revenue in statistically significant for the three types of firms and that the effect decreases in magnitude with firm size, although not substantially so. The largest effect is observed for small companies, which increased revenues by around 24% on average. There is no clear pattern for employment or assets, but the impact of profits is a clear function of firm size. Smaller saw no statistically significant change in their profits and a statistically significant decrease in their return on assets, a finding which is compatible with larger being more able to pass-through the costs of carbon emissions onto their customers, and smaller abatement costs.

Table 19. Effects by company size

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*Small	0.2407***	0.1426**	0.0356	-58.9778	-0.0261**	0.2099
	(0.0726)	(0.0556)	(0.0993)	(78.6265)	(0.0120)	(0.1975)
ETS* Medium	0.2239***	0.0938**	0.0538	320.1253**	0.0173**	-0.0760
	(0.0428)	(0.0377)	(0.0335)	(148.2137)	(0.0078)	(0.1709)
ETS* Large	0.2058***	0.1362***	0.0476*	1078.0257**	0.0050	0.0000
	(0.0413)	(0.0393)	(0.0285)	(536.0457)	(0.0081)	(.)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	28830	28049	33894
# firms	3766	3766	3765	2270	2278	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.5.3. Effect of the EU ETS by geographic region

97. We classify countries in our dataset into four different regions: West (Austria, Belgium, France, Germany, Netherlands, UK), East (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia), North (Denmark, Estonia, Finland, Latvia, Lithuania, Sweden, Norway) and South (Greece, Italy, Portugal, Slovenia, Spain). We then explore the heterogeneity of the impact of the EU ETS by region. Results are reported in Table 20.

98. We find some differences in the impact of the EU ETS across European regions. The effect on revenue appears greater in Southern and Eastern Europe than in the West or the North. The increase in investment in fixed assets is particularly pronounced in Eastern Europe and in the North, but much smaller and not statistically significant in the West and the South. Interestingly, the EU ETS led firms in Southern regions to increase employment, but also increased the probability of firm closure. Therefore, the EU ETS might have forced unproductive firms out of the market, which could have helped more productive firms to expand. The opposite pattern is found in Northern Europe: the EU ETS has reduced the probability that participating firms close down, but conditional on surviving it led to a small drop in the return on assets. The overall pattern, however, suggests that no region was particularly hit by the regulation.

Table 020. Effects by region

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*West	0.1202**	0.0384	-0.0227	1082.7496*	0.0108	0.0134
	(0.0512)	(0.0485)	(0.0330)	(600.8037)	(0.0115)	(0.2727)
ETS* North	0.1212*	0.1285**	0.0845	-476.8863	-0.0324***	-0.9182**
	(0.0639)	(0.0609)	(0.0671)	(447.9180)	(0.0122)	(0.3742)
ETS* South	0.1949***	0.0337	0.0863**	244.8658	0.0015	0.3831*
	(0.0412)	(0.0325)	(0.0372)	(293.0073)	(0.0076)	(0.2250)
ETS* East	0.1958***	0.1894***	0.0227	-49.7124	0.0024	0.0324
	(0.0554)	(0.0495)	(0.0460)	(328.0082)	(0.0092)	(0.2994)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	42834	41666	33894
# firms	3766	3766	3765	3758	3766	3766

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.5.4. Effect of the EU ETS by country

99. In order to dig deeper into the geographical heterogeneity of the impact of the EU ETS, we also report results by country. The small number of observations in some small countries prevents us from accurately measuring the impact in all countries of the sample. Therefore, we limit the results to those countries where the total number of firms (EU ETS and control firms) is greater than 50. These countries include Belgium, Czech Republic, Finland, France, Germany, Italy, Poland, Romania, Spain, Sweden and the UK. Results are reported in Table 21. We caution against over-interpreting these results because of the risks associated with multiple testing (the more statistical tests are made, the more likely is it that some erroneous inferences occur, i.e. false positives).

100. The main result that comes out of this analysis is that no single country experiences a negative impact on revenue, fixed assets, employment or profits. However, we observe the presence of heterogeneity in the impact of the EU ETS across countries, but this heterogeneity differs across outcomes. The revenue effect appears quite stable across countries, while the reaction in terms of investment differs markedly, from no effect in Belgium to over 50% increase in Romania (although the latter coefficient is not very precisely estimated). Poland, Romania and Sweden stand out, with positive and statistically significant impacts on both revenue and fixed assets.

Table 21. Effects by country

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
Belgium	-0.0596	0.0023	-0.0185	-651.8400	-0.0035	0.9130**
	(0.1662)	(0.1325)	(0.0672)	(1524.8134)	(0.0318)	(0.4024)
Czech Republic	0.2233*	0.1770	0.0867	271.3773	-0.0015	0.8193**
	(0.1238)	(0.1428)	(0.1168)	(632.5690)	(0.0210)	(0.3976)
Germany	0.2065***	0.0268	0.0528	2489.7163**	0.0206*	n.a.
	(0.0577)	(0.0534)	(0.0480)	(1001.2702)	(0.0110)	
Spain	0.1206**	0.0062	0.0485	99.2487	-0.0033	0.4606*
	(0.0494)	(0.0382)	(0.0321)	(382.6199)	(0.0110)	(0.2416)
Finland	0.1722**	0.1522	0.0917	-203.7241	-0.0086	n.a.
	(0.0760)	(0.1145)	(0.1715)	(506.7708)	(0.0125)	
France	0.1810	0.2490***	-0.0163	-590.9961	-0.0218	-0.3555
	(0.1130)	(0.0904)	(0.0602)	(1040.1394)	(0.0282)	(0.3472)
UK	0.1710	0.0100	-0.0302	3128.6314**	0.0414*	-0.4547
	(0.1079)	(0.1087)	(0.0647)	(1410.1396)	(0.0240)	(0.4534)
Italy	0.2475***	0.0339	0.1470**	570.7922	0.0104	0.2194
	(0.0705)	(0.0592)	(0.0658)	(508.7892)	(0.0115)	(0.2665)
Poland	0.2145***	0.1901***	0.0377	335.6147	0.0186	-0.3127
	(0.0505)	(0.0552)	(0.0505)	(471.9550)	(0.0114)	(0.3978)
Romania	0.4342*	0.5717***	0.0355	-939.7458	-0.0410	n.a.
	(0.2595)	(0.2099)	(0.1659)	(892.1113)	(0.0300)	
Sweden	0.1783***	0.1956**	0.1172	-265.3195	-0.0458**	n.a.
	(0.0571)	(0.0770)	(0.0794)	(892.6133)	(0.0197)	
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	42834	41666	24842
# firms	3766	3766	3765	3758	3766	3766

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.5.5. Effect of the EU ETS by sector

101. We classify firms in our dataset into seven different sectors: paper, petroleum and coke, chemicals, non-metallic minerals (e.g. glass, ceramics, cement & lime), basic metals, electricity and heat, and others, which basically includes all manufacturing firms that are regulated by the EU ETS not because of the sector they belong to but because they burn fuel on site. We then look at the heterogeneity of the impact of the EU ETS by sector. Results are reported in Table 22.

102. The first notable result is that no single sector has on average experienced a negative impact from the EU ETS. Although some point estimates for some sectors are negative, they are never statistically significantly so. This does not preclude the possibility that some individual firms in some specific countries or sectors may have been negatively affected, but these impacts are too narrow to be statistically detectable. We also find that the positive effect of the EU ETS on revenue is driven by four sectors: minerals, metals, electricity and heat and others, with a particularly high impact in Metals. Overall, the electricity and heat sector is the one that seems to have most benefited from the EU ETS, with statistically significant increases in revenue, assets, employment and return on assets,

a finding which is compatible with windfall profits stemming from the combination of cost pass-through and free allocations.

103. As has been shown empirically, in many European countries the full carbon cost is passed through to output prices (Fabra, Natalia, and Mar Reguant, 2014[44]; Sijm, Jos, S. Hers, Lise Wietze, and B. Wetzelaer, 2008[45]; Harrison Fell, Beat Hintermann, and Herman Vollebergh, 2015[46]; Beat Hintermann, 2016[47]) in particular in the electricity sector which faces little international competition. In the meantime, however, over 99,8% of emission allowances were allocated for free during the first phase and 97% during the second phase (J Schleich, K Rogge, R Betz, 2009[48])so that companies effectively received large public subsidies. Since electricity prices are determined by marginal costs of the marginal production technology, the opportunity costs created by free allowances were also included in electricity prices and led to an increase in firms' profits, a phenomenon that has been labeled "windfall profits" (Lise, Wietze, Jos Sijm, and Benjamin F. Hobbs, 2010[49]; Sijm, Jos, Karsten Neuhoff, and Yihsu Chen, 2006[50]). Hence, it is possible that cost pass-through in the electricity sector partly explains our finding that the EU ETS led on average to an increase in revenues and returns on assets of regulated companies in that sector.

Table 22. Effects by sector

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
Paper	-0.0521	0.0111	0.0947	473.9245	-0.0051	0.1719
	(0.0985)	(0.0855)	(0.0690)	(513.9240)	(0.0174)	(0.2836)
Petroleum & Coke	0.1467	0.6680	-0.0824	-2238.4093	0.0277	4.6166***
	(0.6270)	(0.7138)	(0.2813)	(3080.4521)	(0.1035)	(0.6563)
Chemicals	-0.1460	-0.0714	-0.0924	-1434.9053	-0.0189	-0.1958
	(0.1061)	(0.1029)	(0.0617)	(1258.8872)	(0.0257)	(0.4028)
Non-Metallic Minerals	0.2082***	0.1478***	0.0337	274.8659	0.0092	0.0678
	(0.0549)	(0.0446)	(0.0455)	(335.9877)	(0.0118)	(0.2499)
Basic Metals	0.6022***	0.0242	0.1648**	3839.8139*	0.0158	-0.0577
	(0.1827)	(0.1206)	(0.0727)	(1970.8729)	(0.0403)	(0.5248)
Electricity & Heat	0.2645***	0.1154***	0.0980***	501.4165	0.0144***	0.2903
	(0.0375)	(0.0392)	(0.0332)	(330.0100)	(0.0056)	(0.3237)
Other	0.1788***	0.0779*	-0.0048	383.2083	-0.0084	0.2804
	(0.0455)	(0.0401)	(0.0352)	(394.9285)	(0.0085)	(0.2723)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	42834	41666	33152
# firms	3766	3766	3765	3758	3766	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

5.5.6. Effect of the EU ETS on sectors deemed at risk of relocation

104. An important concern of policy makers is the impact that the EU ETS could have on competitiveness, resulting in job losses. In order to protect industry from potential relocation risks, a list of sectors deemed at risk of carbon leakage was designed by the European Commission, and companies operating in these sectors qualify for free allowances while others progressively have to resort to auctioning. Here we explore the

relative performance of companies considered "at risk" by the European Commission depending on whether they were included in the EU ETS. To do so we create interaction variables between the EU ETS dummy variable, the post-treatment dummy variable and an additional dummy variable equal to one if the company belongs to one of the sectors considered "at risk". Results are shown in Table 23.

105. Focusing on the interaction between the post-treatment dummy and the "at risk" dummy, results show that companies operating in sectors at risk of carbon leakage indeed experienced difficulties compared to firms not judged at risk: after 2005, their assets decreased by around 17%, employment went down by around 13% and profits also decreased in absolute terms (but not when divided by assets, which decreased even more). This suggests that sectors considered at risk by the European Commission indeed operate in fiercely competitive markets and face difficult economic times. Interestingly, within this group, companies regulated under the EU ETS performed relatively better than their non-ETS counterparts, as shown by the positive and statistically significant coefficients on the first results line of Table 23. This indicates that the distribution of free allowances may have more than compensated EU ETS firms at risks for the induced carbon abatement costs of the regulation.

Table 23. Effects on sectors deemed at risk of relocation

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.	Log(revenue)	Log(assets)	Employees	Profit	ROA	Closure
Estimator	OLS	OLS	Poisson	OLS	OLS	Probit
ETS*post*At risk	0.2258***	0.1875***	0.1537***	983.0069***	0.0225**	0.0646
	(0.0548)	(0.0523)	(0.0554)	(370.5131)	(0.0091)	(0.1530)
post*At risk	-0.0692	-0.1740***	-0.1374***	-687.8468***	0.0167**	0.0973
	(0.0432)	(0.0391)	(0.0349)	(241.5098)	(0.0067)	(0.1064)
ETS*post	0.1091***	0.0391	0.0009	47.3670	-0.0068	0.1658
	(0.0282)	(0.0248)	(0.0252)	(260.6806)	(0.0059)	(0.2254)
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes	No
Country F.E.	No	No	No	No	No	Yes
Sector F.E.	No	No	No	No	No	Yes
# obs.	42742	42640	40117	28830	28049	33894
# firms	3766	3766	3765	2270	2278	

Note: *,**,**= significant at 10%, 5%, 1%. Standard errors clustered at the firm level.

6. Conclusion

106. This paper explores the joint impact of the European Union Emissions Trading System, Europe's flagship climate change policy, on both carbon emissions and economic performance based on a combination of macro and micro data collected from various sources.

107. We investigate the causal impact of the EU ETS on carbon emissions using installation-level data from the national PRTRs of France, the Netherlands, Norway, and the United Kingdom. Applying a matched difference-in-differences study design, we find that the EU ETS led to a statistically significant reduction of carbon emissions in the range of 10 – 14%. This result is robust to various sensitivity checks. In line with findings of previous studies, most of the reduction is found in the second trading phase from 2008 to

2012. These results seem to be primarily driven by large installations. Among the economic sectors analysed, the chemical sector shows the largest reductions. We also find that allocating free emissions allowances significantly reduces the treatment effect. Our results suggest that emissions would have declined by around 25% if only half of the allowances would have been freely distributed.

108. We then turn to investigating the impact of the EU ETS on the economic performance of regulated businesses. To do so, we rely on microdata and a matched difference-in-differences study design. We compare close to 2,000 ETS firms over time with unregulated firms within the same country and sector and with comparable turnover, fixed assets, employment and profit in the 3-year period preceding the introduction of the EU ETS. The EU ETS and non-EU ETS groups of firms experience parallel trends in all of these outcome variables prior to the introduction of the EU ETS, suggesting that the control group offers a valuable counterfactual against which to analyse the causal effect of the EU ETS. We find that, contrary to what could have been expected, the EU ETS led to a statistically significant increase in revenue and in fixed assets of regulated firms, and this result is robust to various sensitivity tests.

109. Further research is needed to explore the drivers of these findings. At present, we can only observe that they are in line with widely available evidence of cost pass-through of carbon prices in various EU ETS sectors despite generous free allocations, and with previous evidence that the EU ETS induced regulated companies to increase R&D activity in carbon-saving technologies. They are also compatible with the Porter hypothesis, but further analyses will shed light on these issues. We can, however, conclude with a high degree of confidence that the EU ETS seems to have so far led to carbon emissions reductions with no negative impacts on the economic performance of regulated firms and thus on the competitiveness of the European industry.

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Annex A.

Table A.1. Sectors, UNFCCC categories and NACE codes

Sector name	UNFCCC category	NACE code
Electricity and Heat	1.A.1.A	35
Petroleum and Coke	1.A.1.B / 1.A.1.C	19
Basic Metals	1.A.2.a / 2.C	24
Chemicals	1.A.2.c / 2.B	20
Pulp and Paper	1.A.2.d	17
Non-metallic Minerals	1.A.2.f / 2.A	23