The effect of the EU ETS on firms' investments protecting the environment

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Abstract

This paper investigates the causal effect of the European Emissions Trading Scheme (EU ETS) on firms' investments mitigating pollution, using firm-level panel data on French manufacturing sectors from 2001 to 2016. This paper shows that the EU ETS entailed an increase of low-carbon investments in the third phase, suggesting that the EU ETS finally brings regulated firms towards a cleaner production path and is thus dynamically efficient. In addition, the EU ETS led to a decrease in investments dedicated to pollution not related to greenhouse gases, such as sewage or waste, indicating that EU ETS firms favor investments that mitigate air pollution compared to other environmental damages.

1 Introduction

In December 2019 for the annoucement of the European Green Deal, the Commission President Ursula Van der Leyen claimed that Europe would become the "first climate-neutral continent in the world by 2050". The roadmap set by the European Green Deal is ambitious, considering that between 1990 and 2018, Europe reduced greenhouse gas emissions by 23% only. The transition towards a climate-neutral economy will require considerable efforts by firms to cut emissions, notably by investing into emission-efficient technologies. The European Emission Trading Scheme (EU ETS) is the main policy instrument for the European

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Commission to lead firms towards a cleaner production path. Launched in 2005, the EU ETS is the largest cap-and-trade in the world, covering 45% of European greenhouse gas emissions among 31 countries. In addition to reducing emissions cost-effectively on the short-term, one main objective of the EU ETS is to foster the adoption of low-carbon technologies among firms such that abatement costs are minimized in the long run. The way a policy instrument spurs technological development is crucial to economists, as it relates to the long-term efficiency of the instrument (Jaffe et al. 2003; Stavins, 2008) and to regulators, as it makes the instrument politically acceptable. Despite the ambitious abatement targets set by the European Commission, several issues concerning the EU ETS indicate that incentives to invest into emission-efficient technologies have been inadequate. One of the main issue was the price of the allowance that dropped to zero in 2007 and remained below 10 euros/ton CO_2-eq from 2012 to 2017, due to a surplus of pollution permits. The European Commission and the scientific community acknowledged that the price has been too low to effectively lead regulated installations towards a climate-neutral path (European Commission, 2015; van den Bijgaart et al., 2016). If firms started the transition towards low-carbon production, one following question is how do firms actually operate this shift. The precise way firms move to climate-neutrality is difficult to grasp for several reasons. Firms have various possibilities to comply with the EU ETS: They could buy permits, reduce directly their energy consumption or cut emissions by limiting production for instance. Rather than focusing on emissions abatement directly, this paper takes a different perspective and inquires whether EU ETS firms invested more into low-carbon technologies. Martin et al. (2016) insist on the necessity to explore further how firms react to carbon pricing in terms of low-carbon technology as it relates to the dynamic efficiency of the trading scheme.

Moreover, this study explores the indirect effect of the EU ETS on investments that mitigate other sources of pollution, such as waste or sewage. Firms covered by the EU ETS are not only emitting greenhouse gas emissions but are often generating other environmental externalities. This paper examines whether decisions regarding greenhouse gas abatement are interlinked with the way firms manage their environmental impact in general. In a survey conducted on UK manufacturing firms, Martin et al. (2012) show that climate-friendly firms tend to have a manager who supervises firm's environmental policy. The internal organization of these climate-friendly firms reveals that decisions regarding all types of pollution are centralized and thus may be related. Studying the impact on investments mitigating other types of pollution allows us to discuss further the effectiveness of the EU ETS, which may influence other negative environmental externalities that firms generate. On top of that, considering all aspects of pollution highlights the substantial heterogeneity of the investments between industries and indicate that sectors face different technical constraints.

This paper relies on firm-level data from the French manufacturing industry from 2001 to 2016 and estimates the causal impact of the EU ETS by fixed effects regression. The dataset combines the Antipol survey with information on the general characteristics of firms. The Antipol survey provides yearly data on firms' investments made to reduce pollution, that is divided between different types such as air pollution, waste, sewage, noise etc. We consider that air pollution investments are a proxy for low-carbon investments and find that the EU ETS increased these investments in the third phase. The effect is even stronger for low-carbon investments that entail modifications of the production process, thus revealing that firms make abatement decisions with long-term perspectives. Concerning the other pollution sources, this study finds that the EU ETS reduced the investments into other pollution categories, such as sewage or waste, potentially indicating that firms reallocated their environmental expenditures towards more air pollution abatement due to the cap-and-trade. These crowding out effects vary at the sectoral level, indicating that sectors face substantially different constraints regarding pollution abatement.

Our contribution to the literature is twofold. First, this paper adds to the empirical literature on emissions trading schemes. Regarding the EU ETS, several papers look at the effect on emissions and economic performance using micro-level data. Faye Ndoye et al. (2011), Dechezleprêtre et al. (2018) and Marin et al. (2018) follow this approach and assess the impact of the EU ETS on several indicators of economic performance for European firms. None of these studies find a negative effect on economic performance, while Marin et al. (2018) detect a positive effect on firms' mark-ups. Wagner et al. (2014a) use data on French manufacturing firms and do not find a negative impact of the EU ETS on general economic performance. Besides, Wagner et al. (2014a) do not find a substantial effect on emissions, underlining the lack of stringency of the EU ETS. Similarly Wagner et al. (2014b) focus on German manufacturing firms and conclude that the EU ETS neither altered economic performance nor led to more abatement.

Second, this paper adds to the literature that analyzes the effect of policy instruments on technology. This literature is broad, both from a theoretical and empirical perspective[1] and encompasses the notions of adoption and innovation. Regarding technology adoption and the EU ETS, the few papers on that aspect conclude that firms opted for small-scale changes like fuel-switching (Hoffmann, 2007; Delarue et al., 2008). Löfgren et al. (2014) focus on the Swedish manufacturing sectors and examine the impact of the EU ETS on carbon-reducing investments until 2008. Their paper brings no evidence that the EU ETS fostered low-carbon investments, which may be explained by the scarcity of their sample. The Antipol survey used in our paper is similar to Löfgren et al. (2014), however we consider a larger period (2001 to 2016), rely on more detailed information regarding the scale of the investment and explore the effect on other pollution categories. The study made by Jaraite et al. (2014) on Swedish manufacturing firms from 1999 to 2008 also examines the effect of the EU ETS on firms' environmental investments. Close to our findings, Jaraite et al. (2014) conclude that the EU ETS lowered the investments mitigating other than air-related pollution and raised the expenditures related to air pollution. Their interpretation is that the EU ETS led firms to reorganize their environmental budget in favor of low-carbon technology. Our paper complements the analysis of Jaraite et al. (2014), by extending the time of the study, allowing for sectoral heterogeneity and exploring in more detail the different pollution categories.

Concerning the interaction between cap-and-trade and innovation, Calel & Dechezlepretre (2016) gather patent data from all EU ETS countries and conclude the EU ETS had only a limited positive impact on low-carbon innovation. Moreover, they do not detect any crowding out effect of low-carbon patenting on general innovation. Calel (2020) analyzes the impact of the EU ETS on abatement technologies, using a British panel data set and argues that the EU ETS has spurred more innovation than adoption. The results from Calel (2020) imply that regulated entities are expecting the trading scheme to become stringent, which drives them to spend more into innovation. Our findings confirm the conclusion of Calel (2020), as we detect a positive effect of the EU ETS on low-carbon investments that require a substantial modification of the production process.

[1]Requate, 2005 surveys the theoretical literature and Jaffe et al., 2003 the empirical one. Marcantonini et al., 2017 review the literature on low-carbon technologies and the EU ETS.

The remainder of the paper is structured as follows. Section 2 provides additional background on the EU ETS and on the Antipol survey. The empirical method is described in section 3 and descriptive statistics are given in section 4. Results are discussed in section 5 and section 6 concludes.

2 Background

2.1 The EU ETS

The entry in the EU ETS depends on criteria defined by the European Commission for the most pollution-intensive sectors. Among these sectors are the power and heat generation plants as well as energy-intensive industries like oil refineries, steel works, iron, aluminium, cement, glass, etc. In 2013, chemical sectors were included as well. Within each sector, entities covered by the EU ETS are the ones above a certain capacity threshold based on the size and the emission-intensity of the plant. For instance, combustion installations are included if their yearly thermal input exceeds 20 MWh or manufacturers of glass are covered if their melting capacity exceeds 20 tonnes per day. The main polluters in the EU ETS are power and heat plants, which account for 66% of the EU ETS total emissions in 2017. The power and heat sectors entailed the largest emissions reduction between 2016 and 2017[2], while emissions in the manufacturing sectors increased by 1.1% (Healy et al., 2018).

The EU ETS is organized in phases and is currently in the third phase (2013-2020). At the end of phase I (2005-2007), the price of the pollution permit dropped to zero, caused by the excess of permits in circulation and the fact that these permits were not transferable to the next phase. As a result, the European Commission reduced the amount of pollution rights by 6.5% for the second phase (2008-2012). Nevertheless, the price of the permit at the end of phase II was below 10 euros/ton CO_2-eq due to the economic downturn in 2008 which reduced unexpectedly greenhouse gas emissions. Again, the European Commission lowered substantially the cap for the third phase and implemented several measures to improve the functioning of the market[3]. Salant (2016) claims that the subsequent amendments worsened

[2]These large emissions reductions are mainly explained by the phasing out of coal of several member countries.

[3]Among these reforms are the Market Stability Reserve (MSR) and the allocation rule for free pollution permits. The MSR, legislated in 2015 and modified in 2018, absorbs the excess of pollution permits on the

the uncertainty on the value of the emission permit, which in turn may have hampered low-carbon investments. Still, the price of the allowance is above 20 euros/ton CO_2-eq since 2019, suggesting that the stringency of the EU ETS has improved. The direction of the effect of the EU ETS on low-carbon investments is not clear according to economic theory and different arguments could lead to opposite conclusions. This paper brings a different perspective using empirical methods and finds that the effect is positive, at least in the third phase of the EU ETS.

2.2 Description of the data

This study uses several sources of information. The data on investments targeting pollution (referred later as pollution investments) comes from the Antipol survey. We combine this survey with general information on firms, such as production levels, total investments and number of employees, provided by the database FICUS-FARE[4]. Installations covered by the EU ETS are identified thanks to the data from the European Transaction Log (EUTL). This database is freely accessible and associates each French entity with a unique identifier code that is used in all other surveys or administrative datasets. The sample is restricted to installations that entered the EU ETS in 2013 the latest. We aggregate the data from the EUTL and from the Antipol survey at the firm level, since the variables from the FICUS-FARE files are at the firm level. One firm is considered as regulated as long as one of its installation is covered by the EU ETS. Treated units are the firms covered by the EU ETS and control units are the ones outside of the cap-and-trade. The initial sample includes 172 treated firms and 982 controls. The final sample includes 168 treated firms and 445 control firms. The way the final sample is built is described in section 3.

2.2.1 Pollution investments

The Antipol survey is collected yearly by the French National Statistical Institute[5] on a sample of industrial installations with more than 20 employees. We restrict the sample to the

market. The allocation rule for free allowances, introduced in 2013, reduces the amount of free permits in general and distributes permits depending on the emission-intensity of the installation.

[4]For the years 2001 to 2007, the database is called FICUS. Starting from 2008, the database is called FARE.

[5]In French, it is called INSEE which stands for Institut National de la Statistique et de l'Administration Economique.

manufacturing sectors (rev.2 NACE codes 10 to 33). The Antipol survey covers measures taken by installations to reduce the pollution generated by their activity. Pollution is divided into six categories that are: Sewage, waste (excluding nuclear waste), air, noise and vibration, activities affecting soil and water, activities affecting the landscape and the biodiversity. Installations report the amounts invested to mitigate each type of pollution. In the following, we refer to the different pollution investments as sewage investments, waste investments, etc. Air pollution investments are a proxy for low-carbon investments, although the category air pollution includes local pollutants and greenhouse gas emissions. The use of the air pollution category as a proxy for low-carbon investments is further discussed in section 5. Figure 1 represents the cumulated sum before 2005 of the pollution investments, depending on the treatment status. Figure 1 also specifies the shares of these investments per pollution category with respect to the total of pollution investments. For instance, air pollution investments consist in 35% of pollution investments for treated firms and around 29% for control firms.

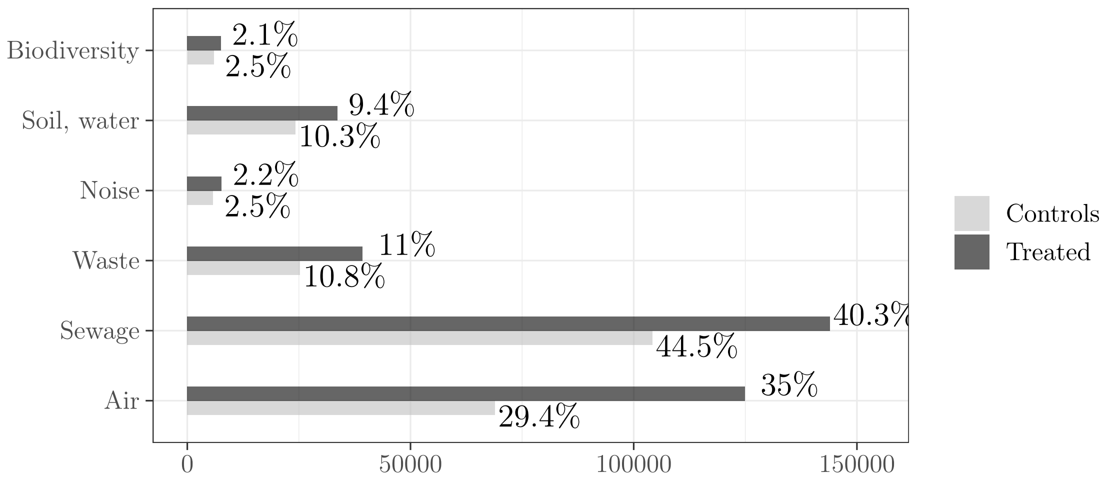


Figure 1: Cumulated sum and shares of investments in kEuros (2001-2004).
168 treated and 445 control firms.

EU ETS firms invest more in all categories in absolute value and the largest difference with control firms is for air pollution. It is worth noticing that even treated firms, which are considered as the largest greenhouse gas emitters in the industry, are not only concerned by air pollution. Treated firms allocated around 40% of their investments to sewage, 35% to air pollution and 11% to waste. Figure 1 points out that firms may not only decide to abate greenhouse gas emissions but also mitigate other negative externalities they are generating, confirming the intuition that the EU ETS may influence all pollution investments. The effect of the EU ETS on other pollution investments could occur in both directions for different reasons.

There are several arguments in favor of a positive effect. First, the EU ETS may induce firms to improve their environmental impact in overall, by raising the environmental awareness of managers or because firms perform better economically thanks to the EU ETS. Concerning the influence of the EU ETS on firms' environmental management, Martin et al. (2012) find that energy-efficient firms tend to have managers that are more concerned by the environment than others, suggesting that firms investing more into low-carbon technologies may put higher efforts to mitigate other environmental externalities. Regarding economic performance, there has been evidence that firms covered by the EU ETS benefit from the regulation, either through the generous permit allocation or through lower energy expenditures (Marin et al., 2018; Ellerman et al., 2016). In such cases, because firms are richer they may allocate more to any kind of investments. This win-win situation refers to the Porter's hypothesis (Porter & der Linde, 1995; Ambec et al., 2013), according which environmental regulation may enhance the competitiveness of the firm.

Several explanations support as well the assumption that the EU ETS lowered other pollution investments. Primarily, if firms' pollution investments are limited by a fixed budget, then the EU ETS would induce firms to favor air pollution investments and diminish others, leading to a crowding out effect (Jaraite et al., 2014). Even if firms do not increase air pollution investments to comply with the regulation, the EU ETS may raise production costs and thus conduct to less spendings for other pollution categories. The fact that the EU ETS augments production costs seems plausible especially in the third phase, after the price of the permit finally picked up and the European Commission limited significantly the cap. Another argument is that the EU ETS would lead firms to become less pollution-intensive and thus requires less efforts to mitigate pollution. For instance, a firm could invest into a clean technology that generates environmental co-benefits, by reducing greenhouse gas emissions and also other types of pollution.

Our results point in the direction of a crowding out effect, indicating that firms reallocated a part of their investments towards more air pollution mitigation. Still, this paper does not claim that firms' environmental impact in domains outside of air pollution is worse, because investments in these domains declined. Less investments could also result from a better management of environmental protection expenditures or from the fact that air pollution investments raise overall pollution-efficiency. The data on investments reveal only one aspect of firms' abatement strategies, requiring to be careful in terms of interpretation. The analysis of the results is discussed further in section 5.

2.2.2 The specific and integrated investments

For each pollution category detailed above, the Antipol survey distinguishes between two types of investments, that are called integrated investments and specific investments. The former category consists in investments in production equipment that provide higher environmental performance compared to the most-used technology. The term integrated comes from the fact that these investments modify the production process. One example related to air pollution is a firm that buys a new machine, like a boiler or an oven, that is less emission-intensive. The integrated invesment decision is associated with the willingness to reduce abatement cost on the long term, as it reshapes the production process and thus may lead to a technological lock-in[6]. Conversely, specific investments reflect short-term investment strategies since they do not modify the production process and are easily distinguishable from it. Specific investments have a preventive or curative purpose and are only used for pollution prevention, such as filters for local pollutant or instruments to monitor emissions. In this study, we analyze the integrated and specific investments for the air pollution category, as it sheds light on the time-horizon of the firm when investing into low-carbon technologies. This distinction between short-term and long-term investments is used in the literature. For instance, Perino & Willner (2019) model theoretically the effect of the timing of allowance allocation on low-carbon investments. They define two types of investments: One that embodies quick changes on a small scale, close by definition to the specific investment category and one that stands for long-term changes on larger scale, comparable to the integrated investments.

[6]Following Arthur (1989), a lock-in effect corresponds to the case where incumbent technologies are maintained although other technologies are superior.

Figure 2 depicts the cumulated sum of air pollution investments that are either specific or integrated, during the pre-treatment period. It indicates that in absolute value, most air pollution investments are specific. Similarly, the shares of specific investments among total air pollution spendings amount to 79% and 67% respectively for treated and control firms. The significant size of specific investments compared to the integrated illustrate that the latter may lead the firm into a technological lock-in and therefore are less implemented.

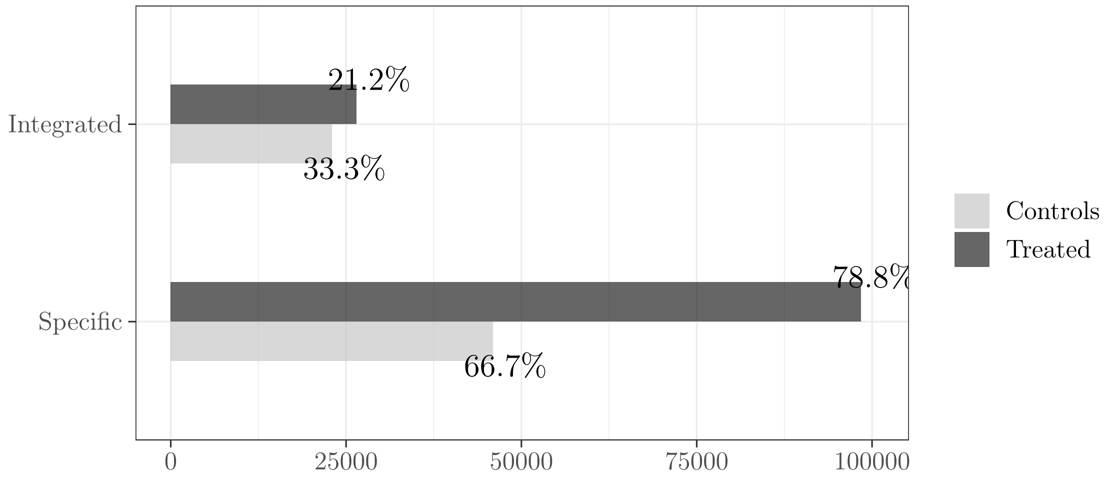


Figure 2: Integrated and specific air pollution investments, cumulated sum and shares before 2005, N=613.

3 Research design

3.1 Identification strategy

Our aim is to estimate the causal effect of the EU ETS on anti-pollution investments. The panel data structure allows us to estimate the following equation:

$$Y_{i,t} = \delta D_{i,t} + \beta X_{i,t} + \zeta_t + \eta_i + \epsilon_{i,t} \quad (1)$$

with $Y_{i,t}$ the dependent outcome for firm i at time t, $D_{i,t}$ the indicator of treatment, $X_{i,t}$ a vector of covariates, ζ_t a vector of year dummies and η_i a vector of fixed effects capturing constant unobserved heterogeneity. $\epsilon_{i,t}$ is the random disturbance term. The treatment is a binary variable such that $D_{i,t} = 1$ if firm i is regulated by the EU ETS at time t and $D_{i,t} = 0$ if not. During the pre-treatment period, corresponding to $t_0 = [2001 : 2004]$, all D_{it} are equal to zero. The post-treatment period corresponds to $t_1 = [2005 : 2016]$. For all $t \geq t_1, D_{i,t} = 1$ if a firm is covered by the EU ETS[7]. The treatment effect δ is estimated by OLS using the within estimator. Considering the large differences between firms covered by the EU ETS and others, it is clear that the EU ETS creates a selection bias. Accordingly we impose some structure on the form of this bias, taking into consideration how treatment is assigned within the EU ETS. The entry into the EU ETS is based on sectoral capacity criteria which are strongly related to the size of the firm (see section 2.1). We assume that the selection bias is fixed in time and captured by the fixed effect η_i. Then the remaining individual heterogeneity that varies in time is assumed to be exogenous from the treatment status, therefore control and treated firms should respond the same way to exogenous shocks. The plausibility of this hypothesis, known as the common-trend assumption[8], can be verified by checking visually whether trends of the outcomes for treated and control are parallel before the EU ETS enforcement. Considering the large discrepancies between covered and non covered firms in our initial sample, we select control units such that firms follow parallel trends before 2005 with respect to the outcome. The selection of control units can be done in several ways. In the literature, it is common to select control units in order to get a balanced sample (Calel & Dechezlepretre, 2016; Calel, 2020; Dechezleprêtre et al., 2018; Marin et al., 2018). We follow the approach of Crump et al. (2009), Dehejia & Wahba (2002) and select control units based on their propensity score.

3.2 Balancing the sample

The propensity score is the probability of receiving treatment, namely $\mathbb{P}(D|X)$, conditional on observables X. The propensity score solves dimensionality issues, by providing a single measure on which to select control units that are close to treated units. The intuition for this measure is that conditional on the observables X, the probability of receiving treatment is

[7] The sample of treated units holds firms that entered in the three phases of the EU ETS. For instance, a firm that entered the EU ETS in 2013 is considered as being covered before.

[8] The common-trend assumption refers to the case where the treatment effect is estimated by differences-in-differences. The differences-in-differences method is a special case of the fixed effect regression with only two periods.

independent of the treatment status. Consequently we should observe that the distributions of the propensity scores between treated and control units overlap, corresponding to the common support assumption. The propensity score is computed using a logit model, on the average of observables during the pre-treatment period. The variables used to compute the propensity score are the following, all transformed in log: the value of production, the number of employees, total general investment, investments made to tackle air pollution. The propensity score is computed on a sample composed of 168 treated units and 982 control units. Table 4 in appendix A.4 details the results of the propensity score for three different specifications. The results presented in section 5 are based on the propensity score from column (1).

Following Crump et al. (2009), we remove control units which propensity score values are lower than 10 times the minimum of the propensity score among treated units. This method, called trimming, allows to make the distributions of the propensity score for treated and controls overlap, as shown in appendix A.5, figure 8. The sample after trimming has 168 treated units and 445 controls. To avoid that the specification of the propensity score drives the final estimates, we conducted the estimations for the two other propensity score models described in table 4, appendix A.4. The estimates with the other specifications are detailed in section 5.3 and confirm that our results hold despite a trimming based on a different propensity score.

3.3 Assumptions

The identification strategy relies on several assumptions as explained above. The main one is the common-trend assumption, that we check visually. Figure 3 displays the common-trends for the investments made by firms to mitigate air pollution. Panel (a) depicts the trend of the average of the log of air pollution investments. Panel (b) and (c) concern respectively the log of air pollution investments that are specific and integrated. Panel (d) gives the trend of the log of all other pollution investments not related to air. The common-trends graphs concerning investments tackling waste and sewage are in appendix A.2, figure 7.

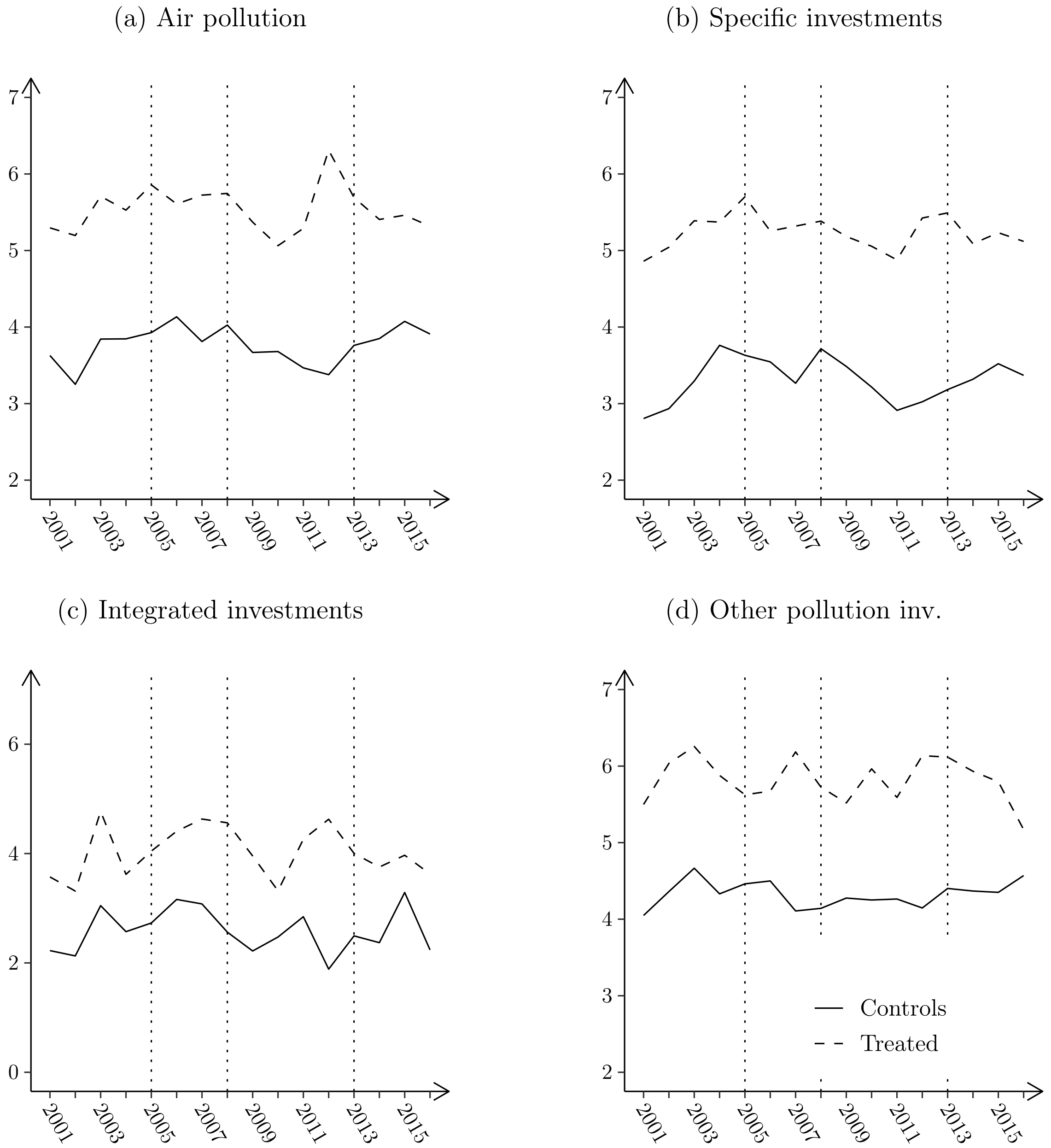


Figure 3: Trends in average log of investments, 168 treated, 445 control units.

A second important assumption is that treatment should not be anticipated by firms and affect the outcome in the pre-treatment period. This hypothesis is testable using years prior to the official start of the EU ETS in 2005. One may define a treatment indicator that switches to 1 for years before 2005 and test whether there is a significant treatment effect during the pre-treatment period. Any evidence of treatment effects prior to 2005 would indicate that some anticipation occured and thus invalidate our results. We test for any anticipation effects and find no evidence for it, the details are given in section 5.3.

Another key assumption is the Stable Unit Treatment Value Assumption (SUTVA). The SUTVA stipulates that all units are independent and therefore the outcome of one unit should not affect directly the outcome of another unit. The SUTVA rules out any spillover or indirect impact that may occur between firms because of the EU ETS. For instance, there may be spillovers if a regulated firm invests into a new energy-efficient machine and leads its neighbor firm to adopt a similar equipment, thus influencing directly the outcome of the other firm as well. An indirect effect could occur if an entity covered by the EU ETS affects other plants through their business relationships, as mentioned by Martin et al. (2016). A typical illustration is the regulation of power plants, that charge higher electricity prices which affect manufacturing firms through their energy bill. Our main concern related to the SUTVA is the possibility of spillovers, since we focus on investments into abatement technologies and that technology adoption is particularly sensitive to spillovers (Martin et al., 2016; Calel & Dechezlepretre, 2016). The SUTVA is not directly testable, although some robustness checks are necessary to make sure that the spillovers or indirect effects are negligible. Since this study is at a preliminary stage, we have not done yet these robustness checks.

4 Descriptive statistics

Table 3 from appendix A.3 describes the sectoral distribution of the initial sample[9]. Following the NACE classification (rev. 2) at the 2-digit level, the mineral products sector, which includes glass and cement producers, and the pulp and paper industry represent the largest share of treated units in the sample (both 26%). The mineral products sector also amounts to 30% of the total of greenhouse gas emissions of the treated units according to the EUTL data. The basic metals producers account for 12% of the treated units but involve the largest share of greenhouse gas emissions (46% according to the EUTL). Table 3 shows that for the most polluting sectors, such as basic metals or mineral products, treated units are greater than controls as these sectors are almost fully covered by the EU ETS.

[9] For confidentiality reasons, we are not allowed to display any information concerning less than three units, which explains why some sectors do not display any information for treated units.

Table 1 provides the mean and standard deviation of several variables for the control and treated firms, as well as the p-value for the t-test, testing for the difference in means between the two groups of individuals. The variable "Total investment" encompasses investments made by the firm in general and not only those related to pollution. The variable "Other pollution investment" concerns investments made by firms to mitigate all different sources of pollution except air pollution. The variable "Share of air pollution" gives the share of air pollution investments among pollution investments. The last column of table 1 indicates that for the six variables, all differences in means are significantly different from zero at the 1% level. These discrepancies highlight the selection bias created by the EU ETS, which covers the largest installations in terms of production, size and investment capacity. Differences in levels in the outcomes are not a significant concern for our analysis, since we postulate that control and treated firms should have similar trends in the dependent variables prior to treatment.

	Control		Treated		
Variable	Mean	Std	Mean	Std	p-value
Number of employees	293.551	4.301	411.250	13.729	0.00001
Production	73,205.730	2,028.404	120,630.000	2,913.154	0
Total investment	3,609.745	284.447	8,183.412	1,579.281	0.003
Air pollution investment	51.568	18.964	226.163	59.587	0.002
Other pollution investment	115.152	19.535	352.047	122.095	0.011
Share of air pollution (%)	26.944	2.431	30.517	3.939	0.130

Note: All amount variables are in kEuros. 168 treated and 445 control firms.
Computed from 2001 to 2004. The p-value corresponds to the t-test diff in means.

Table 1: Summary statistics

Table 1 sheds light on the scale of pollution investments relative to total investments. Computing the ratio of the means from table 1, we find that air pollution investments for treated and control firms, during the pre-treatment period, correspond to 2.8% and 1.4% of total investments respectively. Similarly, other pollution investments amount to 4.3% for treated and 3.2% for controls of their total investments. These simple calculations suggest that in overall, pollution investments involve a tiny part of the spendings of a firm.

4.1 Strong sectoral heterogeneity

Figure 4 depicts the cumulated amounts and the shares of pollution investments during the pre-treatment period for the largest sectors in our sample and highlights the heterogeneity of investments between sectors.

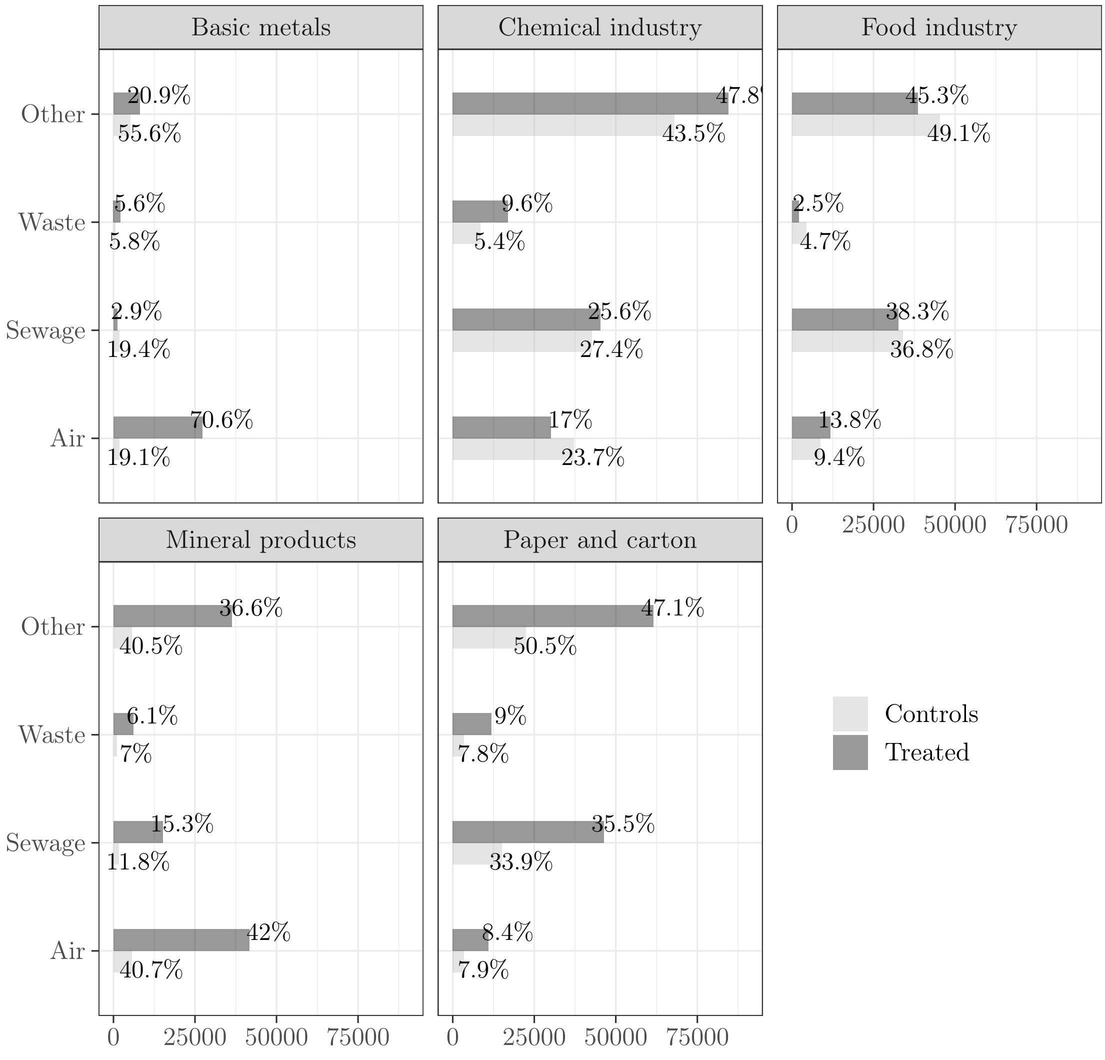


Figure 4: Cumulated sum in kEuros and shares of investments per pollution type and sector before 2005. 168 treated and 445 control firms.

In absolute value, the mineral products' sector which covers cement and glass producers is investing the biggest amounts in air pollution among treated firms. The basic metals' sector invests smaller amounts into air pollution, however 71% of the investments made by treated firms in this sector targets air pollution. Conversely, the chemical industry is mostly dealing with other externalities, such as pollution affecting the soil, water, the biodiversity or generating noise. Similarly, 45% of the investments made by the food industry for treated firms concern other pollution categories and 38% of the investments focus on sewage. The sectoral disparities among treated confirm that the effect of the EU ETS may be heterogeneous at the sectoral level. Therefore we also estimate the treatment effect per sector, as detailed in the following section.

5 Results

5.1 Results per phase

We estimate the causal effect of the EU ETS on different investment variables and for different time periods. This section details only the results per phase. We focus on six dependent variables transformed in log, such that we estimate the percentage change caused by the EU ETS. The first four outcomes are investments dealing with, respectively, air pollution, waste, sewage and other types (this category includes all pollution categories except the air). The two remaining dependent variables are the amount of specific investments and integrated investments, for the air pollution category only. For each regression, we control by the log of wages and the log of total investments. The estimates per phase for these six variables are given in table 2. Results in column (1) indicate that the EU ETS increased on average by 34% air pollution investments in phase III, whereas it had no effect before. The coefficient is statistically significant at the 10 percent level. Columns (5) and (6) shed light on this positive effect. Column (5) reveals that the EU ETS had no impact on specific investments tackling air pollution, while it had a significant and positive effect (1% level) on integrated investments in phase III. Therefore our estimates point out that the EU ETS induced firms to modify their production process in order to abate air pollution. This finding corroborates that the two first phases of the EU ETS provided few incentives towards low-carbon investments. The surge of investments in phase III allows to be optimistic regarding the dynamic efficiency of the EU ETS. Firms could have anticipated that the EU ETS would become more stringent and that from a long-term perspective, investments into abatement technologies would become crucial to meet the regulation at the lowest cost, explaining the results for the third phase.

Columns (2), (3) and (4) pin down some crowding out effects. The EU ETS decreased on average by 28% waste investments in phase II and lowered on average by 39% sewage investments (both significant at the 5% level). Looking at all other investments (excluding air pollution), the EU ETS decreased on average by 32% other investments in phase I (significant at the 10% level). One interpretation, close to the conclusion of Jaraite et al. (2014), is that EU ETS firms operate under some budget constraints and that the rising cost of greenhouse gas emissions induced a reallocation of spendings towards air pollution. The estimates from table 2 also indicate that in the two first phases of the EU ETS, regulated firms reduced investments in other types of pollution while they did not raise investments in air pollution. Until the third phase, the EU ETS may have increased production costs of firms such that they cut other pollution investments and yet have not been stringent enough to spur investments into low-carbon technologies. After 2013, the EU ETS stringency improved thanks to several reforms and therefore stimulated investments into air pollution mitigation. On one hand, the positive results regarding low-carbon technologies highlight the long-term efficiency of the EU ETS. On the other hand, there is some evidence that the EU ETS adversely impacts investments mitigating other types of pollution, which may be a concern for the regulator. The influence on the overall pollution management of firms should then be taken into account when setting the rules of the EU ETS. Considering that the stringency of the EU ETS is expected to rise in the future, it seems crucial to understand to what extent the cap-and-trade may affect the general environmental impact of regulated firms.

	Dependent variable: log investment in					
	Air pollution	Waste	Sewage	Other pollution	Specific air pollution	Integrated air pollution
	(1)	(2)	(3)	(4)	(5)	(6)
Phase I	0.102	-0.130	-0.391**	-0.315*	-0.048	0.176
	(0.168)	(0.139)	(0.183)	(0.178)	(0.154)	(0.133)
Phase II	0.240	-0.283**	-0.210	-0.086	0.155	0.204
	(0.164)	(0.132)	(0.170)	(0.171)	(0.152)	(0.133)
Phase III	0.335*	-0.130	-0.317*	-0.099	0.040	0.374***
	(0.185)	(0.138)	(0.187)	(0.186)	(0.175)	(0.135)
General investment	0.356***	0.149	0.420***	0.455***	0.254**	0.290**
	(0.114)	(0.117)	(0.112)	(0.126)	(0.104)	(0.114)
Wages	0.152	0.104	0.147	0.209*	0.180*	0.044
	(0.094)	(0.081)	(0.109)	(0.117)	(0.094)	(0.073)
Observations	7,977	7,977	7,977	7,977	7,977	7,977

Notes: Robust standard errors clustered at firm level. Year and individual fixed effects. Model within, all in amount variables are in log. 168 treated, 445 controls.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Table 2: Treatment effect per phase

5.2 Heterogeneity

As explained in section 4, we expect the treatment effect to vary depending on the sector. For each dependent variable, we interact the treatment indicator with sectoral dummies defined with 2-digit precision according to the NACE rev.2 classification. The small size of our sample does not allow to add more interaction for the treatment, such as sectoral estimates per phase or per year. In fact, the estimates per sector are already limited by the sample size and should be interpreted carefully. The detailed results are in appendix A.6.1. Figure 9 displays the estimates and the confidence intervals when the dependent variable is respectively the log of air pollution integrated investments, the log of sewage investments and of waste investments.

Concerning the integrated investments, the sectors that are significantly positively impacted by the EU ETS are the textile, paper and carton, rubber and plastic, and electrical machinery industries. The size of the confidence intervals and of some estimates, such as the ones of the rubber and plastic sector (see figure 9a) implies that most sectoral effects are driven by the small number of units within sectors. Nevertheless, the results for air pollution integrated investments point out that for most sectors, the effect is either null or positive. Except for the 'Motor vehicles' sector which estimate is negative, the sectoral treatment effects confirm the previous findings concerning integrated investments.

The estimates for the log of sewage investments and waste investments display more heterogeneity. For instance, the impact of the EU ETS on sewage investments is significant and positive for the basic metals industry (see figure 9b in appendix A.6.1), whereas it is significant and negative for the rubber and plastics producers, the chemical industry or electrical equipment. Concerning waste investments, figure 9c shows that the effect of the EU ETS is positive for the motor vehicles sector, textiles, rubber and plastic industries, while it is negative for electrical equipment, the chemical or pulp and paper sectors. The chemical industry displays substantial crowding out effects, on both waste and sewage investments. This finding is particularly interesting, since this sector is known to be highly pollutant. As a matter of fact, figure 4 in section 4 points out that the chemical industry invests the largest amounts in absolute value to mitigate different sources of pollution.

We find heterogeneity in the treatment effect estimates regarding the investments mitigating other domain of pollution than the air. This implies that depending on the sector, some regulated firms may adjust their investments decisions to increase spendings in favor of air pollution abatement and reduce expenditures towards other negative externalities. The reliability of the estimates are limited by the small sample size. Still, our results establish that firms in different sectors face various constraints regarding pollution abatement and therefore respond to the regulation in a different manner. The sectoral heterogeneity is crucial since it may create some losers and winners (Lyubich et al., 2018), depending on the rules set by the regulation. Our results on investments into other types of pollution highlight that different sectors rely on very distinct technologies and each of them generate negative externalities other than greenhouse gases. It is essential to explore further the degree of heterogeneity of the impact on investments mitigating other types pollution, to get a clear assessment of the effectiveness of the EU ETS on pollution mitigation.

5.3 Robustness checks

In this section, we detail the robustness checks that we have done and those left for future work. First, for the six dependent variables we test whether firms anticipated the EU ETS before 2005. The test consists in adding treatment indicators in equation 1 for years before the legal enforcement of the EU ETS in 2005. If one of the coefficient for a treatment dummy is significant before 2005, then it implies that firms may have reacted in anticipation of the treatment, which violates the exogeneity assumption. For the six dependent variables, we find no evidence of any anticipatory effect, as shown by table 5 in appendix A.6.2.

The selection of units in the sample is based on a trimming process, that relies on a propensity score model. We make sure that our results do not vary substantially if the specification of the propensity score differs, potentially leading to a different sample composition. Table 6 and 7 in appendix A.6.3 display the regression estimates for the propensity score models (2) and (3) respectively. The propensity score models (2) and (3) are described in table 4, appendix A.4.

We also test whether some sectors in the sample drive our results. We remove each sector from the sample and estimate again the treatment effect on the selected sample. The results do not change substantially.

5.4 Discussion of the results

5.4.1 Investments mitigating air pollution

The air pollution category of the Antipol survey includes greenhouse gas emissions such as carbon dioxide (CO_2), nitrous oxide (N_2O) and perfluorocarbons ($PFCs$), that belong to the scope of the EU ETS[10]. Until 2012 the air pollution category includes local pollutant as well, which are not regulated by the EU ETS. Therefore, the use of air pollution investments as a proxy for low-carbon investments may raise concerns. Still, after 2012 the data enables to distinguish between air pollution investments that focus exclusively either on greenhouse gas emissions or on local pollution. Since this distinction appears in the dataset after 2012, we are not able to estimate directly the effect of the EU ETS on investments mitigating greenhouse gas emissions only[11]. We use this information, available only from 2012 to 2016, to check whether our proxy makes sense.

Figure 6 in appendix A.1 indicates that in total during phase III for treated firms, 29% of the air pollution investments limit greenhouse gas emissions, suggesting that even EU ETS firms are mostly concerned with local pollutants. However, the distinction between integrated and specific investments for air pollution reveal that integrated investments are more likely to mitigate greenhouse gas emissions after 2012. Indeed, figure 5 reveals that for both treated and control units, the shares of integrated investments that tackle greenhouse gas emissions are higher than the shares for specific investments. For treated firms, less than 30% of specific investments aiming at air pollution concern greenhouse gases whereas around 47% of integrated investments deal with greenhouse gases. This finding confirms the idea that integrated investments reflect the adoption of clean technologies, while specific investments refer to end-of-pipe technologies like filters, which are more likely to mitigate local pollution. Since our estimates show that the EU ETS spurred integrated air pollution investments rather than specific, this indicates that the EU ETS had an effect on investments dealing with low-carbon technologies.

[10]The EU ETS covers CO_2 emissions since 2005. In 2013, the scope of emissions was extended to N_2O and $PFCs$.

[11]One possibility is to focus exclusively on firms that entered the EU ETS in the third phase and use the year 2012 as the pre-treatment period. In that case, there would be 33 treated units in the sample, which is too small to get any convincing estimates.

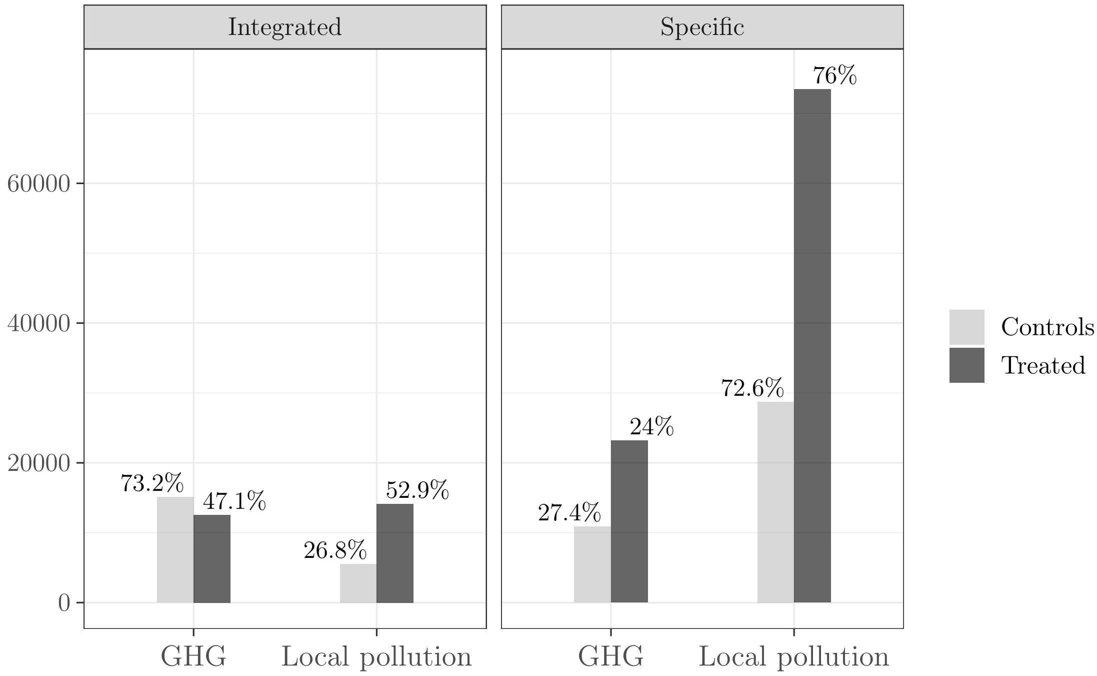


Figure 5: Cumulated sum and shares of investments in kEuros during phase III, 168 treated and 445 control units.

5.4.2 Crowding out effects

A decline of these investments due to the EU ETS does not imply an increase in pollution. Actually, the EU ETS may have had raised the efficiency of firms' regarding all types of pollution and therefore led to less pollution in aggregate. Since limitation of pollution is a main concern for regulation, our results would gain relevance if they could be associated with data on the effective amounts of pollution generated by firms. Especially for the crowding out effects, it would be highly interesting to confront the results with data on the effective amounts of pollution for all categories. Despite this limitation, we consider that the investment decisions shed light on the way firms consider the future regarding pollution abatement. On one hand, the increase of air pollution investments signals that firms anticipate the cost of emissions will become higher. On the other hand, the slowdown of some other pollution investments illustrates that EU ETS firms prioritize air pollution abatement technologies relative to others. However, this priority given to air pollution may enhance the efficiency of the overall environmental impact of the firms and thus generate co-benefits.

5.4.3 Overlapping policies

The chance that other environmental policies overlap with the EU ETS in France is one point we should be careful about. The first concern is that some measures aim at air pollution investments, which is our central outcome of interest. The main law that frames French climate policy is the Energy transition and green growth act[12] enacted in 2015. This law draws the primary objectives concerning carbon emission abatement and establishes guidelines relative to housing, transportation, the energy sector, the industry and households. According to Hainaut et al. (2018) who assess the landscape of low-carbon investments in France from 2011 to 2017, the share of low-carbon investments that are publicly financed within the industry amounts to 14%. Most of the public support stems from two funding schemes. The first one consists in grants allocated by the French Environment and Energy Management Agency (called ADEME in France) to finance energy-saving investments. The second one corresponds to green loans for energy-efficient investments, provided by the Bank for Public Investments (called BPIFrance). Since the two schemes add up to 14% of the total low-carbon investments made in the industry from 2011 to 2017, the conjugate impact of these two schemes compared to the EU ETS seems negligible. Therefore we consider that the risk of estimating the effect of other overlapping policy for air pollution investment is slight.

Nonetheless, some policies in France may target the other environmental externalities we consider in this study, such as sewage or waste management. If firms covered by the EU ETS are also targeted by policy measures that affect these other investments categories, then we may have captured the effect of these measures and not really a crowding out effect. This concern deserves more inquiry and is left for future work.

5.4.4 External validity

The investments reported in the Antipol survey represent a small share of total investments of firms on average, as noticed in section 4 and reported by table 1. A firm may not declare any investments mitigating air pollution and still take substantial measures to reduce its greenhouse gas emissions because of the EU ETS. For instance, an installation may cut its energy consumption or switch from oil to gas, without requiring any specific or integrated

[12] In French, this law is called "Loi de transition énergétique pour la croissance verte" and often mentioned as LTECV.

investment. In that case, we consider that our estimates are conservative in the sense that they only grasp one aspect of the impact of the EU ETS on manufacturing plants. Still, our results indicate that low-carbon investments accelerated in the third phase thus proving that some changes occured. Furthermore, most papers on the EU ETS look at the effect on energy consumption and greenhouse gas emissions but do not use data on investments. This study is complementary to the body of literature focusing on how cap-and-trade affects firms' decisions regarding pollution abatement.

6 Conclusion

This paper brings new insights to the literature thanks to a unique dataset on French manufacturing firms from 2001 to 2016, combining data on pollution investments and on administrative features of the firms. Two main takeways emerge. First, we find that the EU ETS had a positive impact on investments mitigating air pollution in the third phase, which are a proxy for low-carbon investments. These investments involve the modification of the production process, thus revealing that firms are willing to mitigate emissions on the long-term. Such results allow to be optimistic regarding the dynamic efficiency of the EU ETS, which has been questioned several times in the literature and by the general public. Second, this paper shows that the increase in low-carbon investments crowded out investments mitigating other sources of pollution, such as waste or sewage. The crowding out effects are heterogeneous depending on the sector and illustrate that firms are facing substantial different constraints regarding the management of their environmental impact. The slowdown of investments not mitigating air pollution indicate that regulated firms favor spendings that help them to comply with the EU ETS. Although we do not show that the crowding out effects worsened pollution other than greenhouse gases, it reveals that the EU ETS impacts the way firms manage their environmental externalities and therefore may question the effectiveness of the EU ETS.

A Appendix

A.1 Background

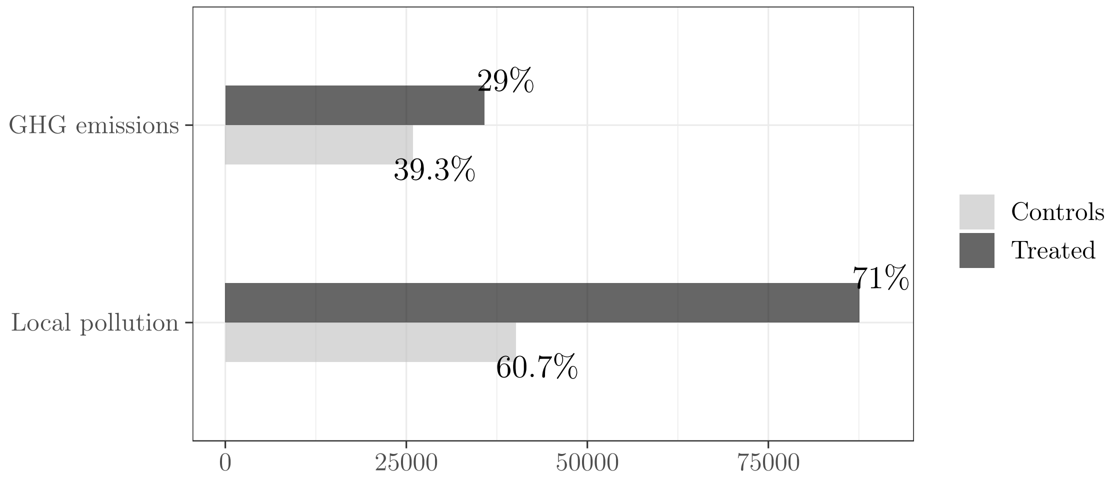


Figure 6: Cumulated sum and shares of investments in kEuros during phase III, 168 treated and 445 control units.

A.2 Common-trend

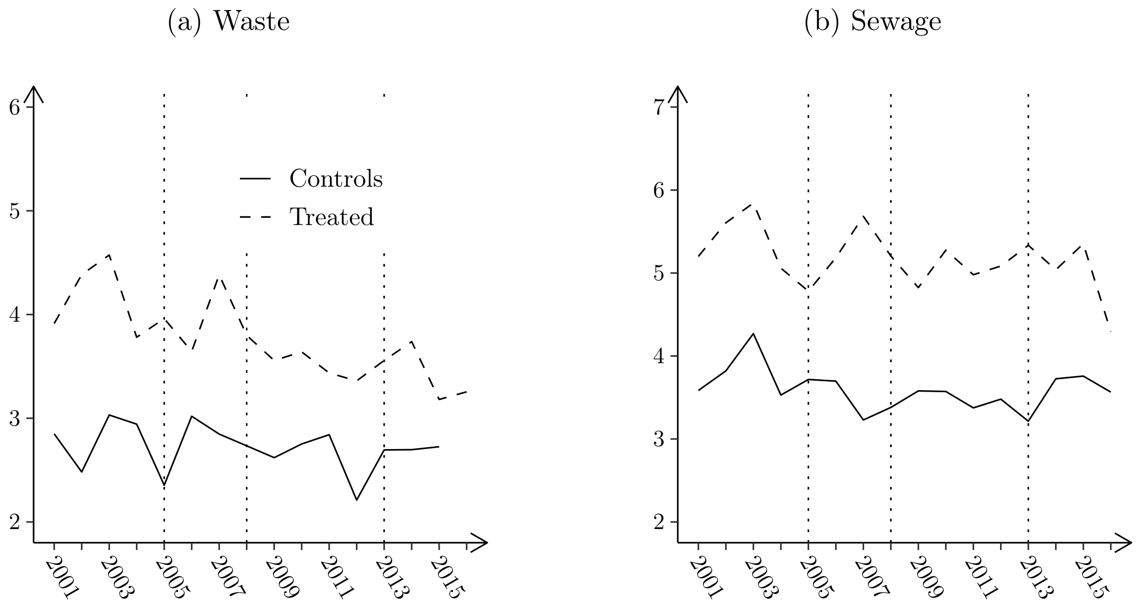


Figure 7: Trends in average investments, 168 treated, 445 control units.

A.3 Descriptive Statistics

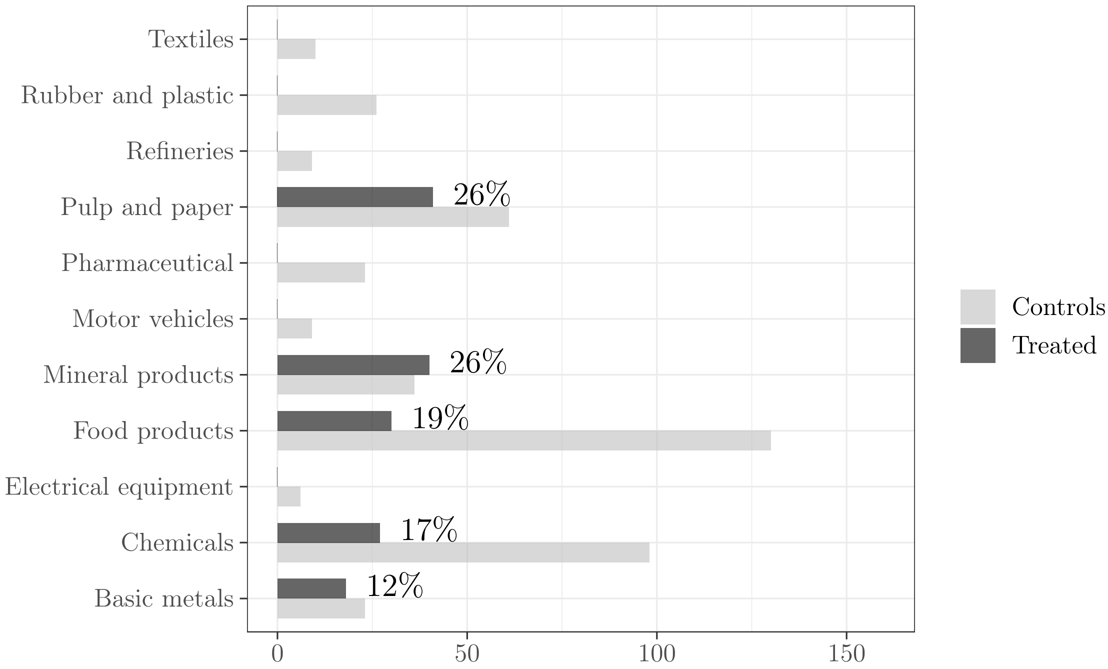


Table 3: Sectoral distribution, 168 treated and 445 controls.

Information for sectors with < 3 units can not be displayed.

A.4 Propensity Score

	Treatment status		
	(1)	(2)	(3)
Production	0.994***	1.061***	1.006***
	(0.253)	(0.264)	(0.245)
Nbr employees	-0.425	-0.564*	-0.354
	(0.282)	(0.293)	(0.275)
Total investment	0.464***	0.294*	0.586***
	(0.155)	(0.150)	(0.154)
Air pollution investment	0.309***		
	(0.082)		
Total pollution investment		0.480***	
		(0.083)	
Sectoral FE	Yes	Yes	Yes
Observations	1,153	1,153	1,153
Log Likelihood	-248.692	-237.714	-255.953
Akaike Inf. Crit.	569.383	547.428	581.905

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.
All variables are in log. 168 treated and 982 control units.

Table 4: Propensity score models

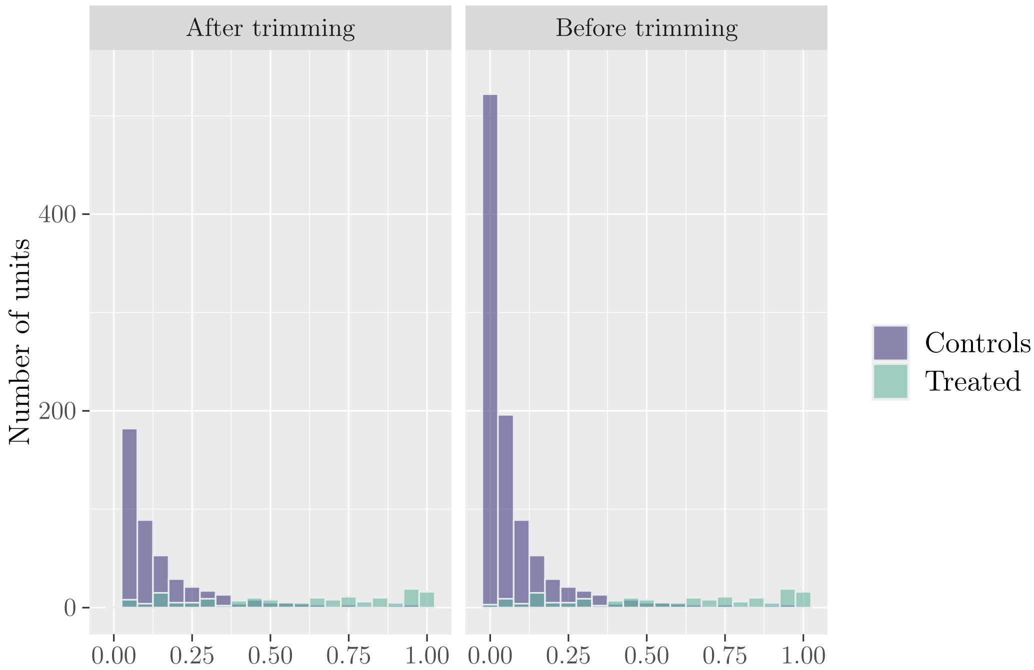
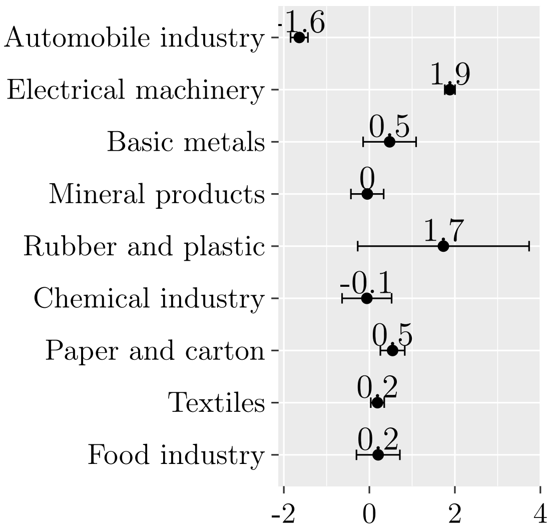


Figure 8: Propensity score distributions, model 1

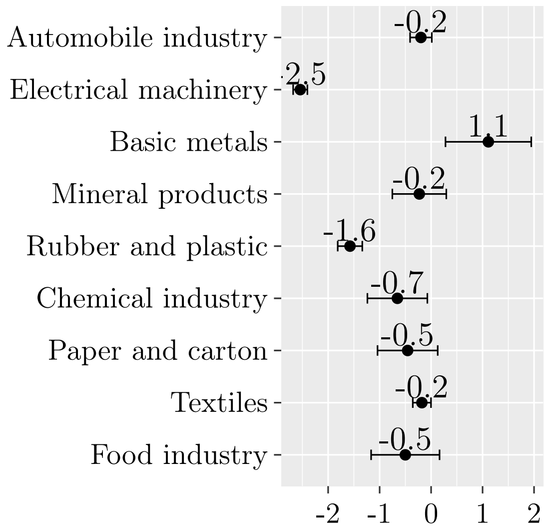
A.5 Common-support

A.6 Results

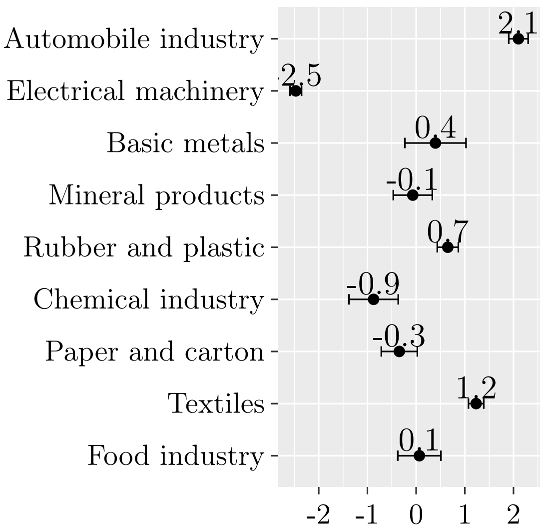
A.6.1 Treatment effect per sector



(a) Integrated investments



(b) Sewage investments



(c) Waste investments

Figure 9: Estimates and confidence intervals for sectoral estimates

A.6.2 Anticipatory effects

	Dependent variable: log of investments in					
	Air pollution	Waste	Sewage	Other pollution	Specific air pollution	Integrated air pollution
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment in 2002	0.107	0.097	0.306	0.181	0.073	0.114
	(0.252)	(0.235)	(0.251)	(0.256)	(0.239)	(0.195)
Treatment in 2003	-0.265	0.326	0.200	0.190	-0.239	-0.048
	(0.277)	(0.246)	(0.260)	(0.258)	(0.276)	(0.199)
Treatment in 2004	-0.114	-0.117	-0.058	-0.203	-0.151	0.087
	(0.264)	(0.235)	(0.269)	(0.276)	(0.253)	(0.194)
Treatment after 2005	0.160	-0.052	-0.180	-0.113	-0.018	0.288*
	(0.214)	(0.187)	(0.221)	(0.231)	(0.207)	(0.155)
Observations	7,977	7,977	7,977	7,977	7,977	7,977

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.
Robust standard errors clustered at firm level
Year and individual fixed effects. Model within.
Control variables (Total investment and wages in log).
168 treated, 445 controls.

Table 5: FE reg robust model

A.6.3 Sensitivity to the propensity score

	Dependent variable: log investment in					
	Air pollution	Waste	Sewage	Other pollution	Specific air pollution	Integrated air pollution
	(1)	(2)	(3)	(4)	(5)	(6)
Phase I	0.154	-0.091	-0.286	-0.198	-0.010	0.184
	(0.166)	(0.138)	(0.182)	(0.177)	(0.152)	(0.131)
Phase II	0.294*	-0.195	-0.091	0.075	0.204	0.223*
	(0.164)	(0.131)	(0.169)	(0.170)	(0.152)	(0.131)
Phase III	0.350*	-0.070	-0.224	0.052	0.063	0.365***
	(0.185)	(0.137)	(0.187)	(0.186)	(0.175)	(0.134)
General	0.379***	0.149	0.403***	0.430***	0.297***	0.258**
investment	(0.108)	(0.111)	(0.111)	(0.120)	(0.099)	(0.110)
Wages	0.149*	0.122	0.153	0.234**	0.159*	0.074
	(0.088)	(0.077)	(0.105)	(0.113)	(0.086)	(0.070)
Observations	8,041	8,041	8,041	8,041	8,041	8,041

Notes: Robust standard errors clustered at firm level. Year and individual fixed effects. Model within, all in amount variables are in log.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Table 6: Treatment effect with propensity score (2)

	Dependent variable: log investment in					
	Air pollution	Waste	Sewage	Other pollution	Specific air pollution	Integrated air pollution
	(1)	(2)	(3)	(4)	(5)	(6)
Phase I	0.075	-0.115	-0.348*	-0.264	-0.068	0.165
	(0.169)	(0.140)	(0.184)	(0.179)	(0.155)	(0.132)
Phase II	0.195	-0.290**	-0.151	-0.048	0.125	0.192
	(0.165)	(0.133)	(0.171)	(0.171)	(0.154)	(0.131)
Phase III	0.261	-0.131	-0.317*	-0.117	-0.001	0.335**
	(0.185)	(0.138)	(0.189)	(0.187)	(0.177)	(0.134)
General investment	0.414***	0.258**	0.428***	0.482***	0.325***	0.200**
	(0.133)	(0.102)	(0.128)	(0.143)	(0.120)	(0.081)
Wages	0.144	0.029	0.122	0.198*	0.159*	0.091
	(0.093)	(0.067)	(0.107)	(0.117)	(0.091)	(0.065)
Observations	7,982	7,982	7,982	7,982	7,982	7,982

Notes: Robust standard errors clustered at firm level. Year and individual fixed effects. Model within, all in amount variables are in log.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Table 7: Treatment effect with propensity score (3)

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