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The impacts of the EU ETS on Norwegian plants' environmental and economic performence

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Effekter av EUs kvotesystem på norske bedrifters klimagassutslipp og lønnsomhet

Marit E. Klemetsen, Knut Einar Rosendahl og Anja Lund Jakobsen

EUs kvotesystem for klimagassutslipp har ikke bidratt til særlig lavere utslipp av klimagasser fra norske bedrifter, viser ny studie. Kvotesystemet har derimot hatt positiv effekt på bedriftenes verdiskapning og produktivitet.

I studien «The impacts of the EU ETS on Norwegian plants' environmental and economic performance» ser forskerne Marit E. Klemetsen, Knut Einar Rosendahl og Anja Lund Jakobsen på effektene av EUs kvotesystem for klimagassutslipp (EU ETS). Forskerne undersøker i hvilken grad kvotesystemet har påvirket utslipp, utslippsintensitet, verdiskaping og produktivitet blant norske bedrifter.

Ikke mindre utslipp

Både kvoteprisen og tildelingen av kvoter har variert betydelig mellom de tre fasene av kvotesystemet (henholdsvis 2005-7, 2008-12, og 2013-20).

Resultatene fra studien viser noen tendenser til negative effekter på utslipp i fase 2, men ingen effekt på utslippsintensitet i noen av fasene. Videre finner forskerne positive effekter på verdiskaping og produktivitet for de regulerte bedriftene i fase 2, men ikke i de to andre fasene. De positive effektene kan skyldes den store mengden gratiskvoter, og at bedriftene i noen grad har overveltet økte marginalkostnader på konsumentene. Resultatene fra denne studien indikerer at norske bedrifter i snitt ikke vil lide økonomiske tap dersom flere kvoter ble auksjonert heller enn tildelt gratis.

Hjørnesteinen i klimapolitikken

Kvotesystemet er regnet som hjørnesteinen i Norges og EUs klimapolitikk, men det har vært reist spørsmål om effektene av systemet. Dette skyldes at kvoteprisene har vært lave, og at bedriftene i stor grad har fått tildelt gratis utslippskvoter.

Tilgang til detaljerte data for årene 2001-13 gir forskerne muligheten til å studere potensielle effekter på bedrifters adferd. Resultatene gir noe støtte for at utslippene blant norske bedrifter falt som følge av kvotesystemet i fase 2, men ikke i de to andre fasene.

The impacts of the EU ETS on Norwegian plants' environmental and economic performance*

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February 9, 2016

Abstract

This paper examines the impacts of the EU Emissions Trading System (ETS) on the environmental and economic performance of Norwegian plants. The EU ETS is regarded as the cornerstone climate policy both in the EU and in Norway, but there has been considerable debate regarding its effects due to low quota prices and substantial allocation of free allowances to the manufacturing industry. Both quota prices and allocation rules have changed significantly between the three phases of the ETS. The rich data allow us to investigate potential effects of the ETS on several important aspects of plant behavior. The results indicate a weak tendency of emissions reductions among Norwegian plants in the second phase of the ETS, but not in the other phases. We find no significant effects on emissions intensity in any of the phases, but positive effects on value added and productivity in the second phase. Positive effects on value added and productivity may be due to the large amounts of free allowances, and that plants may have passed on the additional marginal costs to consumers.

Keywords: Tradable emissions quotas, emissions intensity, productivity, propensity score matching, difference-in-differences
JEL codes: C23, C54, D22, Q54, Q58.

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1 Introduction

Since the establishment of the EU Emissions Trading System (EU ETS) in 2005, emissions trading has been the cornerstone policy instrument to reduce greenhouse gas (GHG) emissions in Europe. The aim of this paper is to investigate how the ETS regulation has affected the environmental and economic performance of Norwegian plants, particularly in the manufacturing industries. The first phase of the EU ETS lasted from 2005 to 2007, the second from 2008 to 2012, while the third lasts from 2013 to 2020. We are mainly interested in whether plants regulated by the ETS have reduced their emissions as a result of the regulation. Emissions reductions can take place by scaling down production or by reducing emissions per output (or both). Thus, we also examine the effects of the ETS on emissions per output, which we refer to as emissions intensity. A positive price on emissions allowances (or quotas) should provide incentives to cut back on emissions. However, the price of allowances has periodically been rather low, moderating these incentives. Moreover, abatement often takes place through investments in new equipments and machinery, which may be driven by expected future emissions prices rather than current prices. Manufacturing plants have received most of the allowances they have used for free, and it is questionable how this have affected plants' incentives to reduce emissions.

We are also interested in estimating the effects of the ETS on economic performance through measures such as value added and productivity. On the one hand, environmental regulation puts constraints on plants (directly or indirectly), suggesting that plants on average are worse off after the regulation. On the other hand, the Porter Hypothesis (Porter and Van der Linde, 1995) suggests that environmental regulation can increase plants' productivity and competitiveness as it provides incentives to innovate. When it comes to emissions trading, the extent of free allocation obviously also matters: If plants receive most of their allowances for free, and are able to pass on most of the marginal cost increase to consumers, they may be better off than without the ETS. The European European Commission (2015) finds that a significant share of the emissions price is passed on to consumers for a number of products regulated by the EU ETS.

There are relatively few econometric studies of the EU ETS, and no such previous studies using Norwegian data (as far as we know). Martin et al. (2015) sum up the empirical evidence for the EU ETS so far, both with respect to emissions and firms' performance, distinguishing between studies using aggregate data and studies using micro-data. Ellerman and Buchner (2008) use aggregate data to empirically examine the effects of the two first years of the EU ETS (2005-06). They find that some emissions reduction took place, tentatively 2.5-5 percent. Similar conclusions are obtained by Egenhofer et al. (2011) for the years 2008-09. Anderson and Di Maria (2011) (phase I) and Bel and Joseph (2015) (phase I and II) use panel data based on countries' total emissions to estimate the extent of abatement, and find quite similar results as Ellerman and Buchner (2008) and Egenhofer et al. (2011). Despite the emissions reduction, Ellerman and Buchner (2008) also conclude that a significant overallocation occurred for some sectors and countries in the first phase, i.e., many plants received more allowances than their business-as-usual emissions.[1]

We are aware of only three studies on the effects of the EU ETS using firm or plant level data. Wagner et al. (2014) use plant-level data for France to estimate the effects of the two first phases of the EU ETS. They find evidence of significant emissions reductions in phase II, as well as indications of emissions reductions in phase I. On average emissions were reduced by 15-20 percent. A large share of the emissions reductions were due to increased use of natural gas instead of coal and oil. Similarly, Petrick and Wagner (2014) use plant-level data for German manufacturing firms for the years 2005-10, and find evidence of emissions reductions in the second phase: Emissions were reduced by on average one fifth according to their estimates. Jaraite and Di Maria (2016) also consider the years 2005-10, using plant-

[1] Jaraitė-Kažukauskė and Kažukauskas (2015) show that firms with few installations and less trading experience were less likely to participate in the ETS market in the first phase of the EU ETS, and traded lower quantities of allowances. They point to transaction costs as an explanation for this finding, together with an inclination among smaller firms to use allowances for compliance only. Hence, emissions reductions could be limited despite a positive price on emissions.

level data for Lithuania, finding no reductions in emissions, but a slight improvement in emissions intensity in 2006-7 (their data did not allow them to study effects on emissions intensity beyond 2007). There also exist studies on other emissions trading systems using micro-data, such as Fowlie et al. (2012) who investigate effects of the Southern California's NO_x Trading Program (RECLAIM). The four above mentioned studies exploit that only a subset of plants or firms were selected for program participation and identify the closest match among the plants or firms not selected for participation.[2]

When it comes to economic performance, Jaraite and Di Maria (2016) find no significant impacts of the EU ETS on Lithuanian firms' profitability. Anger and Oberndorfer (2008) use micro-data to estimate the effects of the EU ETS on revenues of German firms in 2005, finding no significant effect. Commins et al. (2011) also use micro-data for European companies to study the effects of the first phase of the EU ETS on firms' performance, finding negative impacts on both value added and productivity. On the other hand, Bushnell et al. (2013) find that stock prices for carbon-intensive manufacturing industries in Europe fell when the price of allowances dropped by 50 percent in April 2006, suggesting that the EU ETS may have had a positive impact on firms' economic performance. Similar findings were obtained by Veith et al. (2009) for electricity generators regulated by the EU ETS.[3]

We contribute to the existing literature in three ways. First, as already indicated there are few econometric studies of the EU ETS using micro-data. Decisions regarding emissions reductions take place at the plant level, and quotas have been allocated to individual plants based on their historic activity (emissions or output) or planned capacity. Thus, studying the impacts of the EU ETS should ideally be carried out at the plant level, which we do using Norwegian data. Second, our specification allows us to compare the effects of the different phases. This is important as allocation rules and quota prices have differed much

[2]Martin et al. (2014) use micro-data to analyze the impacts of the UK carbon tax, finding strong negative effects on energy intensity and use of electricity at manufacturing plants.

[3]Linn (2010) uses stock prices to estimate the effects on profits of firms regulated by the NO_x cap-and-trade program in the eastern US, finding substantial reductions in profit despite free allocation of allowances. There is also a related strand of literature estimating the price drivers in the EU ETS (e.g., Hintermann 2010; Creti et al. 2012).

between phases. Third, our rich data set allows us to control for plant heterogeneity through a number of control variables. For instance, we indirectly control for carbon taxes on fossil fuels combustion, using plant specific data on relative energy prices ("dirty" vs "clean").

Our paper also relates to the large theoretical literature on emissions trading, including the literature on impacts of quota allocation. The seminal paper by Montgomery (1972) shows that both auctioning and lump sum allocation of allowances lead to the same cost-effective outcome (assuming a perfectly competitive allowance market). However, allocation of allowances in the EU ETS has to some degree been conditioned on plants' activity level, and hence may have influenced plants' decisions.[4] The effects of different allocation rules have been studied analytically and numerically by e.g. Böhringer and Lange (2005), Rosendahl (2008) and Golombek et al. (2013). In the third phase beginning in 2013, allocation has shifted towards "benchmarking", or output-based allocation. As shown by Rosendahl and Storrøsten (2015), this gives firms more incentives to reduce emissions intensities than auctioning (or lump sum allocation). On the other hand, it is also possible that foresighted firms correctly anticipated that allocation of allowances would be based on their historic emissions a few years before the ETS was implemented, giving them incentives to *increase* emissions in some years before 2005.[5]

In order to identify the causal effects of the ETS, we exploit that only a subset of the plants were selected for participation. Other plants, at least in the manufacturing industries which we focus on, were mainly left unregulated with respect to GHG emissions, or have been paying a carbon tax (see Section 3.2). Similar to Wagner et al. (2014), Petrick and Wagner (2014), Jaraite and Di Maria (2016) and Fowlie et al. (2012), we use matching methods based on the program participation selection criteria in order to identify a comparable control

[4]For instance, new plants have received allowances for free, whereas plants closing down are no longer entitled to free allowances in the future. This is to some degree intentional, as policy makers in Europe do not want firms to simply relocate to other jurisdictions with lax climate policies. See the substantial literature on carbon leakage, e.g., Martin et al. (2014), Böhringer et al. (2014), Böhringer et al. (2012), Fischer and Fox (2012).

[5]In the first two phases, allowances to Norwegian plants were grandfathered based on their emissions in 1998-2001. For EU countries, the base years differed somewhat. For several EU countries, the base years for allocation in the second phase included 2005, i.e., the first year of the first phase (Hintermann, 2010).

group of plants that were not selected for program participation. Then we use difference-in-differences, and as an alternative, a fixed effects model, to investigate the effects of the ETS while controlling for a number of other important variables.

Our results indicate weak evidence of emissions reductions among Norwegian plants in the second phase of the ETS, but no significant effects of the two other phases. Moreover, we find no significant effects on emissions intensity of any of the three phases. Further, we identify positive effects of the second phase on both value added and productivity.

The rest of the paper is organized as follows. In Section 2 we present some background information on the ETS. Section 3 contains a description of the data and of the variables used in the empirical analysis. The econometric model and the results are presented in Section 4. Finally, Section 5 concludes and suggests some policy implications.

2 The Norwegian and the EU Emissions Trading System

The EU ETS regulates greenhouse gas emissions from energy production and some large manufacturing industries (see Ellerman et al. (2015) for a recent overview). Initially only CO_2 was included, but later other $GHGs$ in selected industries have been added. The number of regulated industries has also increased somewhat over time.

The first phase of the EU ETS (2005-07) is referred to as a pilot phase, covering around 40 percent of CO_2 emissions in the EU (cf. EU's quota directive 2003/87/EF). The allocation of allowances was determined by the member states, but had to be accepted by the EU Commission. Almost all allowances were allocated for free, mostly based on plants' historic emissions ("grandfathering"). Whereas the price of allowances reached high levels in the first half of this period (up to 30 Euro per ton), the price plummeted towards zero in 2007 as it was clear that total allocation of allowances exceeded total emissions during this three-year period.

In the first phase, Norway had an ETS that was not formally linked to the EU ETS.

However, the Norwegian authorities accepted EUAs (i.e., EU ETS allowances) in its own ETS. Thus, Norwegian plants could buy allowances from EU plants, but not vice versa. The trade was very limited, however, accounting for only about 0.1 percent of total emissions by Norwegian ETS plants. As Norway introduced CO_2 taxes in many sectors of its economy in the 1990's, several industries (most importantly the oil and gas industry) were not regulated by the ETS in the first phase although corresponding industries in the EU were regulated by the EU ETS. Merely 10 percent of Norwegian CO_2 emissions, mostly from the processing industries, were regulated by the ETS in the pilot phase. Allocation of allowances was based on plants' emissions in the years 1998-2001. The very limited purchase of EUAs by Norwegian plants may suggest that the overall allocation was quite generous; this is confirmed by the fact that total allocation to Norwegian plants in the first phase exceeded total emissions by 8 percent. It is therefore relevant to ask whether Norwegian plants were facing a positive emissions price at all during phase I. At least the EUA price seems to have played a minor role for these plants, given the negligible trade in allowances between Norwegian and EU plants.[6]

In the second phase (2008-12) the industry coverage of the EU ETS was quite unchanged, except that the aviation industry was regulated from 2012. The allocation of allowances mostly followed the procedure from the first phase. Again the price of EUAs started at quite high levels (above 20 Euro per ton), but following the financial crisis evolved in late 2008, and the subsequent economic recession, the price of emissions dropped to more moderate or low levels (6-17 Euro per ton) for the rest of phase II.

From 2008 Norwegian plants were fully allowed to trade EUAs with EU plants. Moreover, Norway was no longer allowed to exempt indistries from the ETS, such as e.g. the oil and gas industry). In addition, nitrous oxide (N_2O) emissions from production of nitric acid in Norway were opted in. Thus, the share of Norwegian GHG emissions regulated by the

[6]According to the registry of the Norwegian Environment Agency, total trade in allowances between Norwegian plants during phase I amounted to around 2.5 percent of total regulated emissions. Almost 90 percent of this trade took place after the EU ETS price fell and then stayed below 1 Euro per ton in the spring of 2007.

ETS increased to around 45 percent, comparable with the corresponding EU share. The allocation was still based on emissions in the years 1998-2001, but plants with increased production and emissions since the base period received additional allowances for free.

In the third phase (2013-2020) additional industries and gases, such as perfluorocarbons ($PFCs$) from aluminium production, have been included. Around half of the CO_2 emissions and 40 percent of the GHG emissions in the EU are now regulated by the EU ETS. The allocation rules have been harmonized across member states, and an overall EU cap has been set. Whereas almost all allowances were given out for free in the first phase, and more than 90 percent in the second phase, electricity generation is no longer entitled to free allocation (except in some member states). Other industries still get large amounts of allowances, though, especially if they are categorized as significantly exposed to carbon leakage. The allocation rule has shifted towards mostly output-based allocation ("benchmarking"), based on plants' output in the years 2007-08. The price of EUAs has initially been low (3-9 Euro per ton in 2013-15), partly because of the continued economic downturn and partly because a large share of allowances in the second phase was banked to the third phase.

Norway was allowed to auction a larger share of its allowances in the second phase, but the EU harmonization in phase III also applies to Norway. Hence, whereas the Norwegian oil and gas industry did not receive any allowances for free in phase II, they received a substantial number in phase III (as did manufacturing industries).

Figure 1 illustrates the development over time in total emissions of CO_2, N_2O and $PFCs$ (measured in CO_2 equivalents) from all Norwegian manufacturing plants regulated by the EU ETS in 2013. Total CO_2 emissions from these plants have shown little variation during the estimation period, and were in 2013 2.6 percent below the level in 2004 (the last year before the ETS was implemented), but 1.8 percent above the level in 2001. The highest level was observed in 2010, shortly after the financial crisis in 2008-09. Emissions of N_2O, which were regulated by the ETS from the second phase, declined substantially from 2005 to 2009, whereas emissions of $PFCs$, which were regulated from the third phase, declined

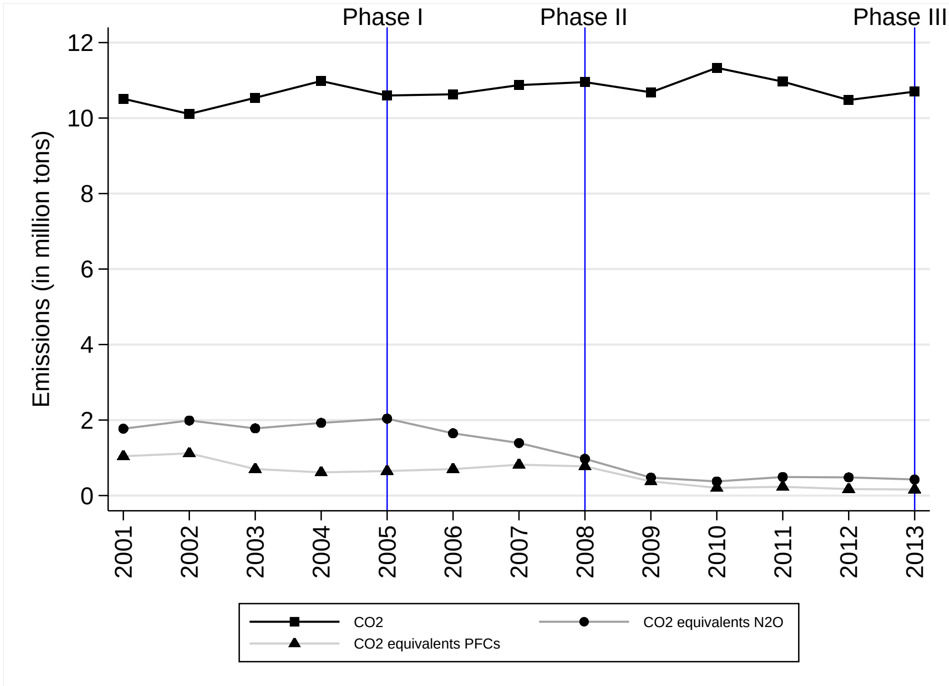

Figure 1: Total annual emissions of CO_2, N_2O, and $PFCs$ (in million tons of CO_2-equivalents) from Norwegian manufacturing plants regulated by the ETS in 2013.

significantly from 2008 to 2010. As a consequence, total GHG emissions from the regulated plants have declined notably since the ETS was established in 2005, but at least for some plants the emissions reductions took place before they became regulated by the ETS.

Figure 2 illustrates the trend in yearly mean prices along the right-hand vertical axis and the annual mean plant emissions along the left-hand vertical axis. The emissions curves are phase specific, so that for instance the curve "Phase II plants" shows how plant emissions (on average) have developed over time for plants that were regulated from phase II and onwards. The figure seems to indicate a small reduction in mean plant emissions for phase I plants from 2005 and for phase II plants from 2008, but emissions were on average declining also the year before phase I and phase II plants became regulated. In order to examine the effects of the regulation, we have to identify a relevant comparison group and also account for the variation in other variables than the ETS regulation.

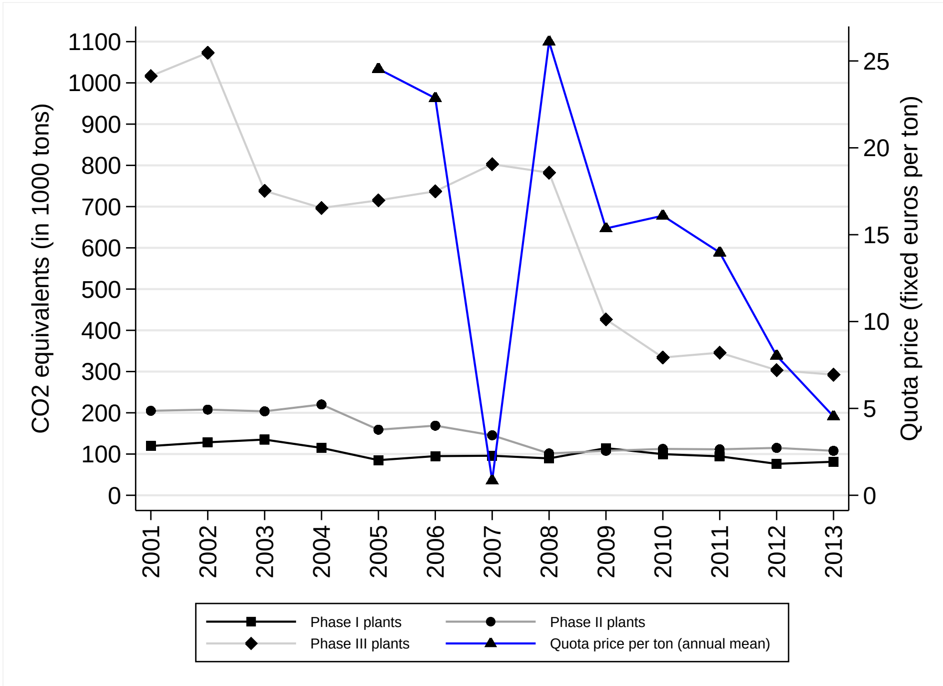

Figure 2: Annual mean emissions of CO_2, N_2O, and $PFCs$ (in 1000 tons of CO_2-equivalents) of ETS regulated plants in the manufacturing industries (left hand axis) and real (deflated to 2013) ETS quota prices (right hand axis)

3 Data sources and description of variables

We have constructed a plant-level panel data set that draws on several data sets from different sources. All data sets are merged using organizational number of the subsidiary as the plant identifier. The data span 13 years, from 2001 to 2013. A key data set comprises the data from the Norwegian Environment Agency (NEA) on annual emissions of all Norwegian plants regulated by the Norwegian ETS or the Norwegian Pollution Control Act, including emissions of CO_2, N_2O and $PFCs$ (measured in CO_2 equivalents).[7] This data set allows us to identify whether the plant is regulated by the ETS or not, and in which phase they enter.

The data mentioned above are supplemented with annual plant level data containing information on number of employees, man hours, value added, energy use and prices, industry

[7] According to the Norwegian Pollution Control Act, pollution is in general prohibited, but plants can apply for pollution permits. The emissions data are publicly available on the Norwegian Environment Agency's website.

affiliation, and more. The data originate from different registers at Statistics Norway: Data on energy use for manufacturing, mining and quarrying; data on structural business statistics for manufacturing, mining and quarrying. The data set thus cover the industries B-C in the Standard Industrial Classification (SIC2007). A detailed description of the key variables is provided below, grouped into two main categories: Emissions, emissions intensity, value added and productivity; and Control variables, including other relevant GHG regulations.

3.1 Emissions, emissions intensity, value added, and productivity

We study the effects of the EU ETS on several dependent variables: Emissions, emissions intensity, labor productivity, and value added. Our main measure of a plant's annual emissions includes CO_2, N_2O and $PFCs$ emissions, all measured in tons of CO_2 equivalents. We also consider an alternative measure of emissions that only include CO_2.

Ideally, emissions intensity should be calculated as emissions relative to output produced (e.g., emissions per ton of steel or per ton of cement). However, as the type of output differs across plants and industries, it is challenging to compare output quantities across plants. Moreover, we do not have data for the quantities produced, only the value of production. Emissions intensities calculated as emissions relative to production value would be sensitive to changes in the output price. A common measure of emissions intensity is therefore emissions relative to the number of employees (see e.g. Wagner et al., 2014). However, such a measure does not take into account that some employees have part-time positions, are on sick leave, work extra hours, etc. Hence, it may be better to use man hours instead of number of employees. In our main estimations we calculate emissions intensities as emissions relative to man hours. This is not an ideal measure, as a plant could increase or decrease its labor intensity during our estimation period. Thus, in Section 4.3 we also consider an alternative measure of emissions intensities, calculated as emissions relative to electricity use (measured in kWh per year). However, as the ETS should give incentives to switch between different energy goods, such as replacing coal or oil with electricity, our preferred specification is emissions relative to man hours.

Value added at factor prices is the plant's annual gross production value minus the cost of intermediates plus subsidies and minus taxes (except VAT). Production value is defined as turnover corrected for changes in stock of finished goods, work in progress and goods and services bought for resale. Cost of intermediates is the value of goods and services used as input in the production process, excluding fixed assets. Our measure of value added is an official measure taken from Statistics Norway.[8] The value added in NOK is deflated using the Producer Price Index (PPI) with 2013 as the base year.

Productivity should be measured as output produced relative to the use of input. Again, good measures of output is challenging to obtain as plants produce different types of goods, and we only have data on production value, not quantities produced. Despite this shortcoming, we use the value added at factor prices as a proxy for output. This measure has the advantage that it is comparable across plants. Further, we use man hours as a proxy for input, so that plant productivity is equal to labor productivity, i.e., value added at factor prices per man hour.

3.2 Control variables

Contrary to studies at the industry level, we are able to take into account plant heterogeneity in our analysis, and thereby reduce the problem of omitted variable bias. This relates both to plant characteristics, and to external factors for the plant such as pre-tax prices and carbon taxes.

Until the ETS was implemented, the cornerstone of Norwegian climate policy was a non-uniform carbon tax implemented in 1991, with exemptions for many energy-intensive manufacturing industries. As mentioned earlier, emissions regulated by the carbon tax were exempted from the ETS in the first phase but not in the second phase (e.g., pulp and paper production and oil and gas production). Only the oil and gas industry had to pay carbon

[8] A more detailed description of the measures are available at the homepage of Statistics Norway.

taxes in addition to being regulated by the ETS from 2008.[9] As the carbon tax has only been implemented on the use of fossil fuels, we indirectly control for this tax through plant-specific relative energy prices: First, prices of petroleum, coal, gas and electricity are calculated as the plant's expenses on the respective energy good (in NOK) relative to the corresponding energy content (in kWh). Then the relative energy price at the plant level is calculated as the price of "dirty" energy (weighted petroleum, coal and gas prices) relative to the price of "clean" energy (electricity). Electricity is characterized as clean since there is no emissions from electricity use and also since renewable power (mainly hydro power) accounts for more than 95 percent of Norwegian electricity production in the estimation period. Changes in relative input prices can provide incentives for input factor substitution towards relatively inexpensive input factors (Hicks, 1932).[10]

Besides the ETS and the carbon tax, there have been arrangements between the Ministry of Climate and Environment and the processing industry in Norway to reduce aggregate GHG emissions (i.e., emissions not covered by the ETS or the tax). These arrangements covered e.g. N_2O emissions from the production of nitric acid and $PFCs$ emissions from aluminium production, which were both later regulated by the ETS (since respectively 2008 and 2013). One arrangement had a target for the year 2007, while the follow-up arrangement had a target for the period 2008-12. According to the Norwegian Ministry of Climate and Environment (2014, p. 98), reductions in N_2O emissions from the production of nitric acid, due to the use of a new technology, was sufficient to fulfill the first arrangement. Thus, it is difficult to know whether these arrangements have had any influence on emissions, and how the arrangement may have incentivized emissions reductions at the plant level.

When it comes to plant characteristics, we use the number of employees as a measure of plant size. Common trends in emissions are controlled for using time dummies (one for each phase). All determinants of emissions intensity at the industry level are controlled

[9] Domestic aviation, which was included in the ETS from 2012, also pays a carbon tax.

[10] As changes in the carbon tax show up in changes in the relative energy price, this means e.g. that the estimated effects of the ETS for plants that were initially regulated by the tax, at least in principle apply to the effects of the ETS as such, and not to the net effects of replacing the carbon tax with the ETS.

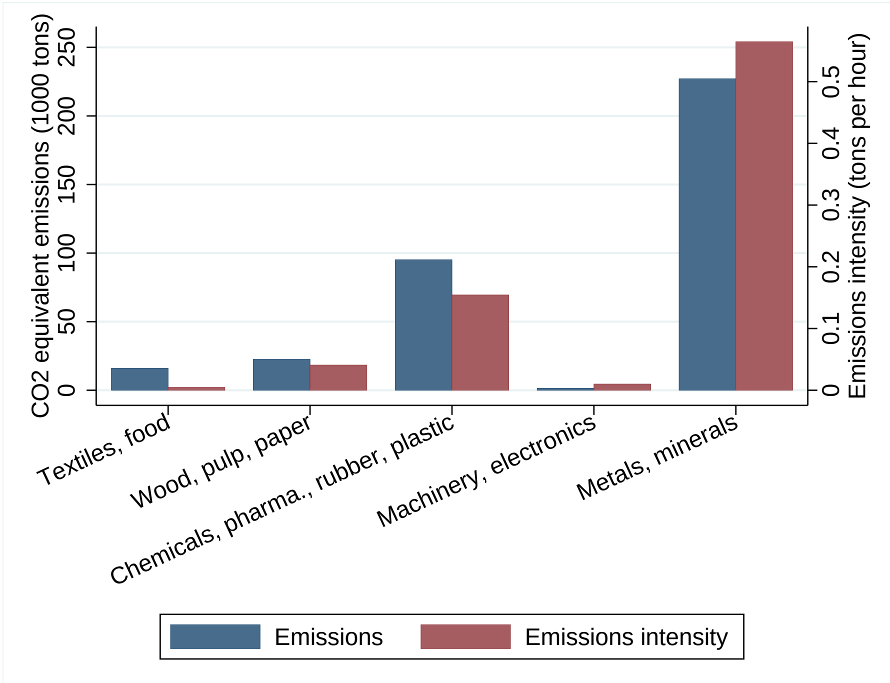

Figure 3: Mean plant emissions and emissions intensities (emissions per man hour) across aggregated manufacturing industries. CO_2, N_2O and $PFCs$ measured in CO_2 equivalents.

for through the use of industry dummies (the aggregated industries are listed in Table 3 in Section 3.3). Figure 3 shows the plants' mean emissions and emissions intensity of CO_2, $PFCs$ and N_2O (all measured in CO_2 equivalents) per aggregated manufacturing industry in the estimation period. We see that plants in Manufacturing of metals and minerals have the highest emissions and also the highest emissions intensities. Plants in Manufacturing of chemicals, pharmaceutics, rubber and plastic also have high emissions and emissions intensities compared to the other four aggregate industries shown in the figure.

3.3 Sample summary statistics

Our initial sample of 665 incorporated Norwegian plants contains 4872 plant-year observations. Of these, 150 plants are regulated by the ETS at least one year. A small franction of the regulated plants are in industries other than the manufacturing industries or Mining and

Table 1: Summary statistics[1] before matching, 2001-2013

	ETS plants		Non-ETS plants	
Variable	Mean	Median	Mean	Median
CO_2, N_2O and $PFCs$ emissions[2]	271,544	50,341	3,886	60.7
CO_2 emissions	177,695	47,340	3,835	47.9
CO_2, N_2O and $PFCs$ emissions intensity[2]	12.3	.19	.133	.0006
CO_2 emissions intensity	12.1	.18	.132	.0006
Labor productivity[3]	.541	.412	.625	.324
Number of employees	211	161	125	77
Relative energy prices ("dirty" over "clean")	1.05	.86	1.16	.98
Value added[3]	213,260	89,385	74,707	38,736
Electricity use (kWh)	486,111	99,953	23,079	7,114
Man hours	381,436	263,336	203,462	122,597
Wages[3]	102,060	72,922	51,836	30,064
Operating profits[3]	119,672	45,223	51,801	20,583
Number of plant-year observations	150		515	
Numer of plants	1126		3746	

[1]For 665 plants and 4,872 plant-year observations in the manufacturing industries.
[2]All emissions are reported as tons of CO_2-equivalents
[3]All values in million NOK are deflated using the PPI with 2013 as base year.

Extraction. The plant level data from Statistics Norway do not cover these industries, and thus these plants are dropped. The control group is selected from the total population of plants emitting CO_2, N_2O or $PFCs$ using nearest neighbor propensity score matching (see Section 4). Our final unbalanced panel data set consists of 1,567 plant-year observations and 152 plants in the manufacturing industries, 72 of which are regulated by the ETS.

Table 1 presents descriptive statistics and demonstrates how ETS and non-ETS plants differ with respect to the different variables before the matching procedure. Table 2 illustrates the same descriptive statistics for the matched sample, i.e. the treatment and the control group. The matching procedure reduces the differences between the treatment group and the non-treated (the "control group") substantially with respect to almost all variables (the exceptions are labor productivity and relative energy prices, where the differences are quite small in any case). For instance, before matching the emissions intensity of the control group was only 1.1 percent of the emissions intensity of the treatment group. After the matching procedure the emissions intensity of the control group constitutes 11 percent of the emissions

Table 2: Summary statistics[1] after matching, 2001-2013

	Treatment group		Control group	
Variable	Mean	Median	Mean	Median
CO_2, N_2O and $PFCs$ emissions[2]	347,810	53,341	9,530	2,117
CO_2 emissions[2]	138,033	51,300	9,480	1,971
CO_2, N_2O and $PFCs$ emissions intensity[2]	.621	.279	.068	.030
CO_2 emissions intensity[2]	.407	.221	.057	.028
Labor productivity[3]	.57	.31	.42	.30
Number of employees	234.8	188	216.5	168
Relative energy prices ("dirty" over "clean")	1,06	.86	1.33	1.09
Value added[3]	228,832	112,443	105,149	66,663
Electricity use (kWh)	571,235	176,062	65,701	19,205
Man hours	387,927	293,730	301,543	231,761
Wages[3]	91,607	62,522	59,134	38,923
Operating profits[3]	103,752	46,253	68,069	41,252
Number of plant-year observations	743		824	
Numer of plants	72		80	

[1]For 152 plants and 1,567 plant-year observations in the manufacturing industries.
[2]All emissions are reported as tons of CO_2-equivalents
[3]All values in million NOK are deflated using the PPI with 2013 as base year.

intensity of the treatment group. Note that the differences between the treatment and control plants also include any effects from the ETS regulation. As seen from Table 3, there are no plants from the industries Mining and extraction (excluding oil and gas) and Oil and gas extraction in our final data set, which comprises only the manufacturing industries. The reason for this is that the matching procedure does not find any "neighbors" outside the manufacturing industries as nearly all Oil and gas extraction plants are regulated by the ETS, and very few Mining and extraction (excluding oil and gas) plants are regulated by the ETS.[11]

Figure 4 illustrates the mean annual emissions intensities (index) for the matched sample (see Section 4) of plants that operate during the entire estimation period (plants that enter or exit during the estimation period are left out). The figure shows the changes in GHG emissions (CO_2, N_2O and $PFCs$) per man hour for the three different groups of treated

[11]A large share of the regulated plants that are excluded through the matching procedure are oil and gas fields. The time paths of emissions and emissions intensities for these fields are highly influenced by the depletion of the fields' reservoir. See Gavenas et al. (2015) for a study of CO_2 emissions from Norwegian oil and gas fields.

Table 3: Share of plant-year observations across industries, 2001-2013

	Before matching		After matching	
	ETS plants	Non-ETS plants	Treatment	Control
Industry	Percent	Percent	Percent	Percent
Mining and extraction (excluding oil and gas)	0.6	6.3	0	0
Oil and gas extraction	33.4	0.7	0	0
Manuf. of textiles and food	6.5	38.9	8.2	36.5
Manuf. of wood, pulp and paper	14.8	3.8	22.2	8.3
Manuf. of chem., pharmac., rubber and plastic	14.2	19.6	23.2	19.8
Manuf. of metals and minerals	26.2	18.1	46.4	34.4
Manuf. of machinery and electronics	4.3	12.5	.03	1.0
Total	100	100	100	100

(ETS-regulated) plants and for the control group (matched plants not regulated by the ETS). We see that plants included from phase I display increasing trends in emissions intensities until 2004, before phase I was initiated, and then again in 2005-07, before phase II was initiated. On the other hand, emissions intensities for this group decrease substantially when phase I starts in 2005 and when phase II starts in 2008. The increasing trends can possibly be due to adaptations if the plants expect the free quotas to be allocated based on previous emissions. Our empirical specification in Section 4 does not capture such potential adaptations. The decrease from 2007 to 2008 is possibly due to the high quota price in 2008, although we notice a decrease in emissions intensities for both regulated and unregulated plants in 2008. For plants included from phase II, emissions intensities appear to have decreased substantially from 2008 (when phase II started) and onwards. Plants included from phase III display a decreasing emissions intensity trend over most of the period, including 2013 (the year phase III was initiated). As 2013 is the last included year in the data, we cannot observe how emissions intensities have responded after this phase was initiated. Finally, plants which were never regulated by the ETS display similar trends as the plants which were included in phase III.

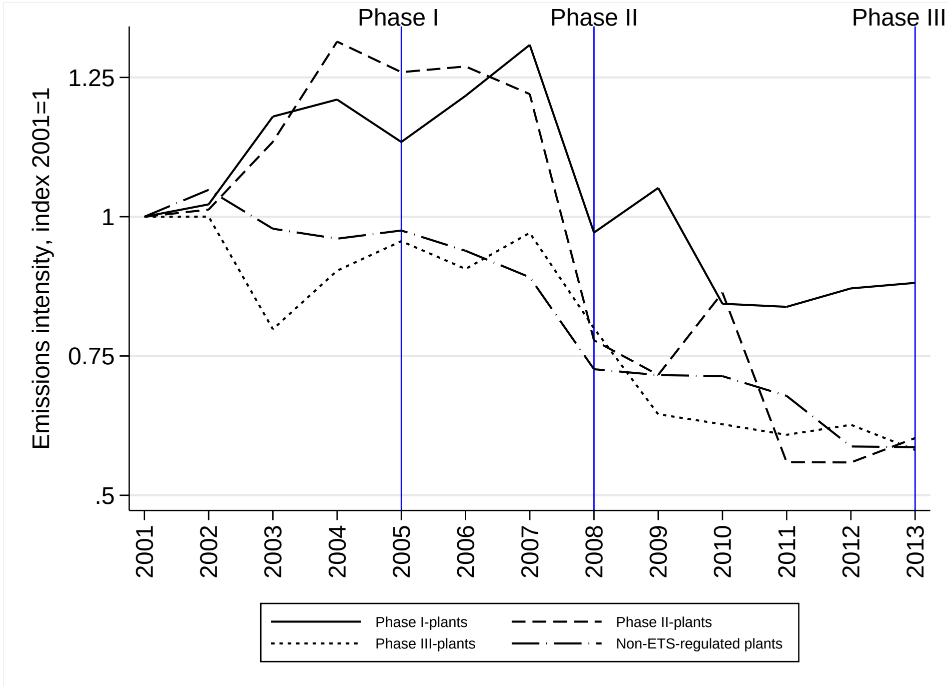

Figure 4: Plant mean annual emissions intensities (CO_2 - equivalent emissions of CO_2, N_2O and $PFCs$ per man hour). Index: 2001=1

4 Empirical model and results

Our main objective is to investigate the effects of the ETS on Norwegian plants' environmental performance (emissions and emissions intensity) and economic performance (value added and productivity). Similar to Fowlie et al. (2012), Petrick and Wagner (2014), Wagner et al. (2014) and Jaraite and Di Maria (2016), we exploit the fact that only a subset of the plants were selected for participation in the ETS. The selection for ETS participation of a plant is based on the type of pollutant, the plant activity (production of specific types of goods) and the capacity limit.[12] We do not observe all these factors for plants that

[12]The capacity limit is specified as e.g. total thermal effect (typically 20 MW), or tons of products (steel, cement etc.) per hour or 24 hours. As the regulator selects plants for participation in the ETS based on the capacity limit, regression discontinuity constitutes as a suitable method for estimating the effects of the ETS (see e.g. Lee and Lemieux (2010)). However, the capacity limit varies with the main activity of the plant, and we do not have comparable data on the activity of the plants in the control group. Also, there is a lot of missing values for the measures of capacity. With an already small sample of Norwegian plants, it would thus not be manageable to use regression discontinuity methods based on the capacity limit.

are not regulated by the ETS. For each plant regulated by the ETS we identify the closest matches among the plants not selected for participation in the ETS based on the propensity score.[13] The propensity score is the probability of receiving treatment conditional on some matching variables. The variables used are proxy measures of the participation requirements of the ETS.[14] In this way we identify a comparable control group of plants that were not selected for program participation. The probability of receiving treatment is conditional on the observed values in the year 2001[15] of the matching variables: We require an exact match[16] on type of pollutant as the ETS only regulates emissions of CO_2, N_2O (from nitric acid production since 2008) and $PFCs$ (from aluminium production since 2013). We also require exact matching on our proxy for plants' type of activity, i.e., the industry affiliation specified by standard industrial codes at the 2-digit level.[17] Finally, as continuous matching variables we include predetermined levels of emissions (as a proxy for capacity limit) and number of employees (as a measure of plant size). As Table 3 illustrates, only plants in the manufacturing industries are included in the estimation sample.

The plants in the control group remained either unregulated (with regard to greenhouse gas emissions) or were regulated by a carbon tax, which we control for through the relative energy price variable. As plants above the capacity limit typically emit more than those below the limit, plants in the control group have lower average emissions than plants in the treatment group (see Table 2 in Section 3.3). However, as we are not interested in estimating absolute changes in emissions levels, but relative changes in emissions and emissions

[13] The matching procedure used is the STATA routine *psmatch2* with 1-10 nearest neighbor matching. We perform a robustness test using 1-3 neighbors (see Section 4.3).

[14] The participation requirements are found in Law on Greenhouse Gas Emissions ("Klimakvoteforskriften").

[15] The EU ETS was initiated in 2005, but was announced some years before (cf. Convery, 2009). In March 2000, a Green Paper on emissions trading was issued by the EU Commission, and hence the year 2000 can be seen as the announcement year of the EU ETS (cf. Wagner et al., 2014). In June 2001, the Norwegian government discussed through a White Paper a possible Norwegian ETS from 2005 (Norwegian Ministry of Environment, 2001). Nine months later, a new White Paper announced the start-up of the Norwegian ETS from 2005 (Norwegian Ministry of Environment, 2002). Hence, the plants' predetermined characteristics in 2001 are used as matching variables. An implication of this is that we do not allow entry of new plants after 2001 in our dataset. The unbalance in the dataset is thus only due to plant exit.

[16] To require an exact match means that the matching procedure is only allowed to pick control plants with exactly the same matching variable value (in this case, a plant that emits the exact same type of pollutant).

[17] We perform a robustness test using the 3-digit level (see Section 4.3).

intensities, the comparability issue is less severe.

We calculate difference-in-differences, and as an alternative estimate a fixed effects model, on the matched sample to investigate the relation between each ETS phase and respectively emissions, emissions intensity, value added, and productivity, controlling for a number of other important variables. The sample average treatment effect is estimated using dummy variables for each phase, which indicates whether the plant participated in the ETS during this phase or not. We henceforth use the subscript i to denote the plant, t to denote year, and p to denote the phase.

4.1 Basic DID

For all four dependent variables (emissions, emissions intensity, value added and productivity), in general denoted Y, we estimate a basic DID. We define

$$E_{it} = \begin{cases} 1 & \text{if} \quad \text{plant } i \text{ is ETS-regulated in year } t \\ 0 & \text{if} \quad \text{plant } i \text{ is not ETS-regulated in year } t \end{cases}$$

Let T_i be the first year plant i is regulated by the ETS, and $\tau(p)$ the start-up year of phase p, respectively 2005, 2008, and 2013 for phase I, II and III.[18] We specify our model in logarithmic form which means that we can interpret the estimates in terms of relative changes:

$$\log Y_{it} = \alpha_0 + \sum_{p \in \{1,2,3\}} \pi_p I\Big(\tau(p) \leq t < \tau(p+1)\Big) + \sum_{p \in \{1,2,3\}} \gamma_p I\Big(\tau(p) \leq T_i < \tau(p+1)\Big)$$
$$+\beta_p \sum_{p \in \{1,2,3\}} E_{it} \times I\Big(\tau(p) \leq t < \tau(p+1)\Big) + \mathbf{X}'_{it} b + \epsilon_{it} \qquad (1)$$

In equation (1) α_0 is the constant term. The next terms are time dummies for each phase.[19] The parameters π_p thus pick up common trends during the phases not attributed to the ETS.

[18] Our data is limited to 2001-2013 and thus we only include the first year of phase III.

[19] We include time dummies for each phase instead of year dummies because of the need for parsimony. This means that the time effects are constrained to be constant within each phase.

The parameters γ_p are phase-group fixed effects that capture the mean difference before treatment between each phase-group (i.e. plants entering in phase I, II and III) and the control group. The phase-group fixed effects thus take into account heterogeneity between groups of plants that enter the ETS in different phases. This can potentially matter, as phase I only included a sub-sample of the plants emitting CO_2, whereas nitric acid production plants emitting N_2O entered from phase II, and aluminium producing plants emitting $PFCs$ entered from phase III.

The parameters of main interest, β_p, capture the treatment effects from being regulated by the ETS in phase p (i.e., whether the plant is regulated in year t interacted with the time dummies). The interaction term, $E_{it} \times I(\tau(p) \leq t < \tau(p+1))$, is thus equal to 1 if plant i is regulated by the ETS in year t and phase p includes year t. Note that plants entering in phase p are assumed to be affected by treatment also in subsequent phases as they remain regulated in the later phases. Moreover, we assume that the effect of phase p regulation is the same for all plants regardless of when they entered the ETS. Our specification takes into account that the quota prices, and also the quota allocation rules, differ between the phases. Hence, also the treatment effects may differ phases. With respect to emissions and emissions intensities, we expect a negative estimate of β_p, to the degree that the plants are incentivized to reduce emissions because of the regulation. For value added and productivity, the effects could go in either direction, and thus we do not have any prior expectation regarding the sign of the estimate of β_p.

The vector $\mathbf{X}_{it}$ contains the control variables described in Section 3.2, including dummies for industries (see Table 3 for a list). The error term, ϵ_{it}, is assumed to be independent of the covariates in $\mathbf{X}_{it}$, the time dummies, the phase group fixed effect, and the treatment variable. Number of employees is lagged by one year $(t-1)$ to avoid the potential problem of reversed causality and to reduce potential problems of simultaneity. The empirical results related to this specification are displayed in columns (1)-(2) in Tables 4 and 5, where we investigate the effects of participation in the ETS on emissions and emissions intensity, as well as in columns (1)-(2) in Table 6, where the effects on value added and productivity are shown. Before discussing the results in Section 4.3, we present an alternative specification.

4.2 Panel data regressions with plant specific effects

It is possible that plant specific effects are not fully taken care of by the phase group fixed effects, which capture the mean difference between the treatment groups (plants entering in phase I, II and III) and the control group not attributed to the regulation (cf. the specification in equation (1)). The validity of equation (1) rests most critically on the assumption that the treatment variables are independent of the unobserved plant specific fixed effects. An endogeneity problem occurs if unobserved variables that affect the dependent variables, also affect the treatment variables. One solution could be to use instrumental variables, i.e., variables that contribute to exogenous variation in the selection into treatment, but do not have an effect on the dependent variables *per se*. However, we are not aware of any variables that qualify as instruments. Instead, the solution we favor is to allow correlation between unobserved plant specific fixed effects, ν_i, and the treatment variables. Rather than simply including group fixed effects to capture the fixed difference between the treatment group and the control group (γ_p from (1)) we therefore include a plant fixed effect (ν_i) in this specification:

$$\log Y_{it} = \sum_{p \in \{1,2,3\}} \pi_p \, I\Big(\tau(p) \leq t < \tau(p+1)\Big) + \sum_{p \in \{1,2,3\}} \beta_p \, E_{it} \times I\Big(\tau(p) \leq t < \tau(p+1)\Big) + \mathbf{X}'_{it} b + \nu_i + \epsilon_{it} \tag{2}$$

The results are displayed in column (3) in Tables 4 and 5 (for emissions and emissions intensity), and in columns (2) and (4) in Table 6 (for value added and productivity). We acknowledge that the basic specification in equation (1) does not solve the simultaneity issues. Most importantly, plants that are regulated by the ETS are likely to be more emissions intensive than plants not regulated by the ETS. Including phase-group fixed effects instead of plant fixed effects will thus lead to positive correlation between the error term and the treatment variables. Hence, the specification in equation (2) is more appropriate for causal interpretations. However, the specification in equation (1) is much more parsimonious, which in particular can matter for such a small data set as we employ here. Moreover, the specification in (1) allows us to control for plant size, relative energy prices, industry specific effects, phase group specific effects and phase time specific effects. We thus argue that the version of the basic difference-in-differences specification in equation (1), where we include control variables (i.e. column (2) in Tables 4-5 and columns (1)-(2) in Tables 6-7), also provides results that can reasonably be interpreted as treatment effects of the ETS.

4.3 Results

4.3.1 Emissions and emissions intensity

The estimated effects of the ETS on emissions are presented in Table 4. Columns (1)-(2) display the results of the basic difference-in-differences specification (1), without and with control variables, respectively, whereas column (3) displays the results of specification (2), i.e., including plant fixed effects. The specification of equation (1) excluding control variables (column (1) in Tables 4-5) is mainly considered for descriptive purposes, as we believe industry effects, plant size and relative energy prices are important drivers of the dependent variables. The estimated coefficients of main interest (β_p) are displayed in the three first rows. The estimate of β_p is the relative change in expected emissions resulting from participation in phase p.

From the results in Table 4, according to all specifications in columns (1)-(3), it appears that phase I had no significant effect on emissions. The same applies to phase III, although the estimated effects are consistently negative in all three specifications. In phase II, on the other hand, we the estimated effects on emissions is negative. In the basic difference-in-differences model in column (1), the estimate (-0.59) is significant at the 5 percent level. This could indicate large decreases in emissions from participation in phase II of the ETS, i.e., around 45 percent ($e^{-0.59}-1 = -0.45$). This is in line with what we observed in Figure 2 above. However, when we add control variables, the estimated emissions reduction is lowered to -0.36 and significant at the 10 percent level (see column (2)). The estimate drops further to -0.33 (significant at the 10 percent level) when plant fixed effects are taken into account, cf. column (3). Overall, we see some tendencies of emissions reductions due to the ETS in phase II.

Next, we test the one-sided hypothesis that there has been no emissions reduction due to the ETS in any of the three phases, i.e., we test the one-sided null hypothesis that $\min(\beta_1, \beta_2, \beta_3) \geq 0$, against the alternative that at least one of the coefficients is negative, i.e., $\min(\beta_1, \beta_2, \beta_3) < 0$. We perform a one-sided test as the expectation from economic theory is that the ETS should cause a negative change in emissions. Based on the test results we can only weakly reject the null hypothesis (at the 10 percent level) and only in the most basic model (column (1)). The p-values range from 10 to 25 percent across the specifications. The test results indicate that the estimated negative effect of phase II could be random. However, if any emissions reduction can be ascribed to the ETS, it likely took place in phase II rather than in phase I or III. Furthermore, we cannot reject the hypothesis that $\beta_1 = \beta_2 = \beta_3$, although in the most basic model in column (1) the p-value is not far from the 10 percent rejection level (14 percent). Moreover, the hypothesis that $\beta_1 = \beta_2 = \beta_3$ is rejected in the robustness test reported in Table 7 (column (3)) in Section 4.3.3 where we only include emissions of CO_2. This indicates that the specification where we allow the effects of the ETS to differ between phases is the most appropriate one.

A possible explanation for the lack of emissions reductions of phase I could be that in this phase, Norway had an ETS that was not formally linked with the EU ETS. As explained in Section 2, Norwegian plants could buy but not sell quotas to plants in EU countries. The extent of buying quotas from EU plants was tiny, which is understandable as the total allocation to Norwegian plants exceeded total emissions by 8 percent during phase I. Hence, it is tempting to conclude that there was no binding cap on emissions from Norwegian plants in the first phase. The lack of effect for phase I could also be related to the fact that this was a pilot phase, and that the plants needed time to adjust to a new regulation. It is also possible that plants expected allocation in future phases to be based on their emissions levels during phase I, in which case there could actually be some incentives to inflate emissions. Moreover, it may take time to adjust to a new regulatory regime. Decisions about activity level and investments in new equipment typically take time, and there may be also be some gradual learning effects about how to reduce emissions in a cost-effective way. Allocation has been quite generous also in phase II and (for most manufacturing plants) in phase III,[20] but as plants have been fully allowed to trade allowances with EU plants as of 2008 (first year of phase II), the ETS price should have been of importance. The price of allowances has changed over time, and was on average much higher in phase II than in phase III. This could possibly explain why we find som indications of an effect of phase II but not of phase III.

[20] In phase III, the allocation rules were changed more significantly, but most of the manufacturing industries still receive close to 100 percent of the allowances they need for free (cf. Section 2).

Table 4: Effects on CO_2 equivalent tons of CO_2, N_2O and PFCs

Response variable:		(1)	(2)	(3)
Log of emissions	Coef.	Est.	Est.	Est.
Treatment Phase I	β_1	-.02	.01	-.07
		(.20)	*(.21)*	*(.17)*
Treatment Phase II	β_2	-.59**	-.36*	-.33*
		(.29)	*(.22)*	*(.20)*
Treatment Phase III	β_3	-.17	-.15	-.13
		(.42)	*(.41)*	*(.39)*
Time dummy Phase I	π_1	-.33**	-.16	-.20*
		(.15)	*(.16)*	*(.11)*
Time dummy Phase II	π_2	-.32**	-.18	-.31
		(.22)	*(.19)*	*(.19)*
Time dummy Phase III	π_3	-.40	-.15	-.44
		(.40)	*(.41)*	*(.41)*
Group fixed effect Phase I	γ_1	3.60***	3.54***	
		(.47)	*(.47)*	
Group fixed effect Phase II	γ_2	2.88***	3.73***	
		(.64)	*(.52)*	
Group fixed effect Phase III	γ_3	4.93***	3.84***	
		(.51)	*(.57)*	
Log of relative energy prices			-.21**	-.07
			(.10)	*(.05)*
Log of number of employees			.97***	.83***
			(.19)	*(.24)*
Plant specific effects	ν_i	No	No	Yes
Plant specific control variables		No	Yes	Yes
Industry dummies		No	Yes	Yes
Number of plant-year obs.		1,454	1,454	1,454
Number of plants		144	144	144
Equation		(1)	(1)	(2)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Treatment plants are matched to control plants based on predetermined values of CO_2, N_2O and PFC emissions, number of employees, and exact matching on industries at the 2-digit level. Column (1) is a basic DID specification. Column (2) is a basic DID with additional control variables. Column (3) is a panel data regression with plant fixed effects and additional control variables.

Tests of hypotheses:

	(1)	(2)	(3)
One-sided test of no effect in any phase:	p-value	p-value	p-value
$H_o:\ \min(\beta_1,\beta_2,\beta_3)\geq 0$	.10	.24	.25
Wald test of equality of coefficients:			
$H_o:\ \beta_1=\beta_2=\beta_3$	.14	.41	.43

Regarding the control variables, we first observe that emissions reductions seem to have taken place in all three phases, independently of the ETS. All estimated coefficients for the time dummies (π_p) are negative, although whether these are significant differ somewhat between phases and specifications. In columns (1)-(2), where fixed effects are at the group level rather than at the plant level, we see that plants entering in phase III have higher average emissions levels than plants entering in phase I and II. Furthermore, the estimated effect of relative energy prices is -0.21 in column (2), significant at the 5 percent level. A 10 percent increase in relative energy prices would according to this result lead to a 2.1 percent reduction in emissions. However, in column (3) the estimate is only -0.07 and not significant at conventional levels. The estimated effect of plant size (log of number of employees) varies from 0.83-0.97 and is significant at the 1 percent level in both column (2) and (3). A 10 percent increase in number of employees thus leads to an increase in emissions by 8.3-9.7 percent, indicating that emissions are close to proportional to plant size. Both these results are as expected.

Next, we investigate the effects on emissions intensity. From the results displayed in Table 5, there appears to be no significant effects of any of the three phases on emissions intensity. The estimated effects of phase I have both positive and negative signs depending on the specification. The estimates of β_2 and β_3 are negative in all specifications, but the estimates are not significant at conventional levels. This may suggest that, to the extent that the ETS participation led to emissions reductions in phase II, this occurred through reduced activity level (and thus emissions) rather than through reduced emissions intensity. This could for instance be the case for some plants if it is costly to reduce emissions per output, and at the same time difficult to pass on the higher costs to the consumers (e.g., because they operate in a global competitive market). Hence, we cannot exclude the possibility that none of the phases have caused any emissions intensity reduction. This is also the conclusion when we test the null hypothesis that there has been no emissions intensity reduction in any of the three phases against the alternative that at least one of the phases had such an effect (i.e., the hypothesis that $\min(\beta_1, \beta_2, \beta_3) \geq 0$ vs. $\min(\beta_1, \beta_2, \beta_3) < 0$).

When it comes to the control variables, we see from Table 5 that none of the estimates corresponding to the time dummies (the coefficients π_p) are significant, with the exception of phase I in the basic model in column (1). The signs of the estimated coefficients are consistently negative across phases and specifications, but we cannot confirm significant changes in emissions intensity independently of the ETS during any of the phases. The positive and significant estimates of phase group fixed effects (γ_p) suggest that plants entering in phase III are more emissions intensive than plants entering in earlier phases (and much more emissions intensive than plants not regulated by the ETS). Moreover, a 10 percent increase in relative energy prices is estimated to reduce emissions intensity by 2.1 percent (significant at the 5 percent level) according to the results of column (2). This is similar to the case of emissions (Table 4). In column (3), however, the estimate is lower and no longer significant. Finally, whereas larger plants (not surprisingly) were estimated to have higher average emissions (cf. Table 4), we do not find significant effects of number of employees on plants' emissions intensity (this is consistent with the close to proportional effect on emissions level in Table 4).

Table 5: Effects on emissions intensities (emissions per man hour)

Response variable: Log of emissions intensity	Coef.	(1) Est.	(2) Est.	(3) Est.
Treatment Phase I	β_1	.13	.03	-.05
		(.19)	*(.21)*	*(.17)*
Treatment Phase II	β_2	-.38	-.32	-.28
		(.26)	*(.22)*	*(.20)*
Treatment Phase III	β_3	-.19	-.13	-.10
		(.43)	*(.41)*	*(.38)*
Time dummy Phase I	π_1	-.24*	-.08	-.11
		(.14)	*(.16)*	*(.11)*
Time dummy Phase II	π_2	-.28	-.15	-.26
		(.21)	*(.19)*	*(.19)*
Time dummy Phase III	π_3	-.32	-.23	-.36
		(.42)	*(.41)*	*(.42)*
Group fixed effect Phase I	γ_1	3.52***	3.52***	
		(.47)	*(.47)*	
Group fixed effect Phase II	γ_2	2.79***	3.78***	
		(.53)	*(.52)*	
Group fixed effect Phase III	γ_3	4.52***	3.84***	
		(.45)	*(.57)*	
Log of relative energy prices			-.21**	-.08
			(.10)	*(.06)*
Log of number of employees			-.02	-.01
			(.18)	*(.23)*
Plant specific effects	ν_i	No	No	Yes
Plant specific control variables		No	Yes	Yes
Industry dummies		No	Yes	Yes
Number of plant-year obs.		1,449	1,449	1,449
Number of plants		144	144	144
Equation		(1)	(1)	(2)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Treatment plants are matched to control plants based on predetermined values of CO_2, N_2O and PFC emissions, number of employees, and exact matching on industries at the 2-digit level. Column (1) is a basic DID specification. Column (2) is a basic DID with additional control variables. Column (3) is a panel data regression with plant fixed effects and additional control variables.

Tests of hypotheses:

	(1)	(2)	(3)
One-sided test of no effect in any phase:	p-value	p-value	p-value
$H_o:\ \min(\beta_1, \beta_2, \beta_3) \geq 0$	.18	.27	.35
Wald test of equality of coefficients:			
$H_o:\ \beta_1 = \beta_2 = \beta_3$	.18	.46	.50

4.3.2 Value added and productivity

We also investigate the effects of the ETS on real value added and (labor) productivity among Norwegian plants. The results are displayed in Table 6. Columns (1)-(2) display the results of the basic difference-in-differences specification (equation (1)), whereas the results in columns (3)-(4) display the results of the plant fixed effect specification (equation (2)). The estimates of β_p now reflect the expected relative change in value added and productivity due to participation in a given phase.

For phase II, the estimated effects on both value added and productivity are positive and significant. In both specifications, the estimated effect of phase II on value added is 0.25 (significant at the 5 percent level), which implies an estimated 28 percent increase in value added. The estimated effect of phase II on productivity is 0.25-0.26 (significant at the 1 percent level in column (2) and at the 5 percent level in column (4)). For phase I and III, the estimated effects on value added and productivity are positive but not significant (across all specifications). However, we do reject the hypothesis that there is no effect on value added and productivity in any of the three phases, in the two-sided[21] null hypothesis that $\min(\beta_1, \beta_2, \beta_3) = 0$, against the alternative that $\min(\beta_1, \beta_2, \beta_3) \neq 0$. The p-values are within the 5 percent level across all specifications.

The positive effects on value addded and productivity of phase II may seem a bit strange as the environmental regulation puts constraints on the plants. However, as discussed in the introduction, there are several possible reasons why the ETS might increase value added and productivity. First, the manufacturing plants receive large amounts of free allowances. If they are able to reduce their emissions at relatively low costs, they can sell excess allowances and earn a profit that possibly exceeds their abatement costs. Moreover, if the marginal costs are (partly) passed on to consumers, their revenue could increase. The fact that we only find significant positive effects in phase II can be due to the relatively higher average quota price in

[21] As economic theory is ambivalent with regards to whether environmental regulations cause positive or negative changes in value added and productivity, we now use a two-sided rather than a one-sided test.

this phase compared to phase III, and the fact that Norway had an ETS that was not formally linked with the EU ETS in phase I. As mentioned in the introduction, Bushnell et al. (2013) show that stock prices for European carbon-intensive manufacturing industries declined when allowance prices were halved in April 2006, suggesting a positive relationship between quota prices and economic performance for the regulated plants. Second, the Porter Hypothesis (Porter and Van der Linde, 1995) points to the fact that environmental regulations give more incentives to innovate, which may spur productivity and competitiveness. However, as this process is likely to take some time, the former explanation may be more plausible.

For all specifications we can reject, within the 5 percent level of significance, the hypothesis that $\beta_1 = \beta_2 = \beta_3$, confirming that the estimated effects differ across phases. Our specification which allows the effects to differ across phases is thus the most appropriate one.

Regarding the control variables, we see that there are significant increases in value added and productivity during all three phases independently of the ETS (see the estimates of π_p). Moreover, the results suggest that plants entering in phase I and phase III are characterized by higher value added and higher productivity than plants entering in phase II and plants never regulated by the ETS (again independently of the ETS). We identify positive and significant effects of relative energy prices on value added and productivity in columns (1)-(2). The estimates are 0.06 in both columns, significant at the 5 percent level, implying that a 10 percent increase in relative energy prices is estimated to increase value added and productivity by 0.6 percent. It is difficult to say whether this result is simply due to lower prices of electricity (recall that the relative energy price is calculated as the price of fossil energy over the price of electricity), or if it is related to the Porter hypothesis. In the model with plant fixed effects in columns (3)-(4), the estimates are positive but no longer significant. Finally, a 10 percent increase in the number of employees is estimated to increase value added by 7.1-9.8 percent (significant at the 1 percent level in both models). Columns (2)-(3) indicates no difference in productivity based on the size of the plant. Hence, we do not observe any scale effects.

Table 6: Effects on value added and productivity

Response variable:	Coef.	(1) Log of value added Est.	(2) Log of productivity Est.	(3) Log of value added Est.	(4) Log of productivity Est.
Treatment Phase I	β_1	.01	.01	.02	.01
		(.11)	*(.11)*	*(.11)*	*(.11)*
Treatment Phase II	β_2	.24**	.26***	.24**	.25**
		(.10)	*(.10)*	*(.10)*	*(.10)*
Treatment Phase III	β_3	.05	.04	.05	.07
		(.17)	*(.17)*	*(.17)*	*(.17)*
Time dummy Phase I	π_1	.29***	.38***	.25***	.35***
		(.04)	*(.04)*	*(.05)*	*(.04)*
Time dummy Phase II	π_2	.47***	.52***	.44***	.52***
		(.05)	*(.05)*	*(.05)*	*(.05)*
Time dummy Phase III	π_3	.50***	.56***	.42***	.55***
		(.14)	*(.14)*	*(.14)*	*(.14)*
Group fixed effect Phase I	γ_1	.48***	.47***		
		(.09)	*(.09)*		
Group fixed effect Phase II	γ_2	.05	.10		
		(.15)	*(.14)*		
Group fixed effect Phase III	γ_3	.65***	.66***		
		(.11)	*(.11)*		
Log of relative energy prices		.06**	.06**	.004	.002
		(.03)	*(.03)*	*(.03)*	*(.03)*
Log of number of employees		.98***	.02	.71***	-.07
		(.05)	*(.05)*	*(.14)*	*(.08)*
Plant specific effects	ν_i	No	Yes	No	Yes
Plant specific control variables		Yes	Yes	Yes	Yes
Industry dummies		Yes	Yes	Yes	Yes
Number of plant-year obs.		1,567	1,564	1,567	1,564
Number of plants		152	151	152	151
Equation number		(1)	(1)	(2)	(2)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Treatment plants are matched to control plants based on predetermined values of CO_2, N_2O and $PFCs$ emissions, number of employees, and exact matching on industries at the 2-digit level. Columns (1)-(2) are simple DID estimations with additional control variables. Columns (3)-(4) are panel data regression with plant fixed effects and additional control variables.

Wald tests of hypotheses:

	(1)	(2)	(3)	(4)
Two-sided test of no effect in any phase:	p-value	p-value	p-value	p-value
$H_o : \min(\beta_1, \beta_2, \beta_3) = 0$	.05	.04	.05	.03
Test of equality of coefficients:				
$H_o : \beta_1 = \beta_2 = \beta_3$	.05	.03	.05	.03

4.3.3 Robustness tests

To investigate the robustness of our findings we perform several robustness tests. First, we replicate Tables 4-5 with emissions of CO_2 only (i.e., excluding N_2O and PFCs). This is a relevant robustness test as relatively few plants have emissions of N_2O or $PFCs$ that are regulated by the ETS. The reason for this is partly that CO_2 emissions are much more widespread than emissions of other greenhouse gases, but also because the ETS has mainly focused on CO_2 emissions. Obviously, this specification is more likely to accurately estimate the potential effects on CO_2 emissions.

The results are displayed in Table 7. In columns (1)-(2) we report the results of the basic difference-in-differences model with control variables, whereas in columns (3)-(4) plant fixed effects are included. First, we identify no significant effects of either phase I or phase III in any of the specifications. This is similar to the results when all three greenhouse gases are included. Second, the estimated effects of phase II are negative across all specifications, but not significant at conventional levels (the lowest p-value of 0.11 is obtained in columns (3)-(4) where we estimate the effects on emissions and emissions intensity including plant fixed effects). The estimated effect on emissions (-0.26) is quite similar to the corresponding estimate in Table 4 (-0.33), i.e., when also N_2O and PFCs are included. In any case, we cannot reject in any specification the hypothesis that there is no effect of any of the three ETS phases on emissions and emissions intensity. However, in columns (3)-(4) we can reject that the effects of the phases do not differ, which validates our specification allowing the effects to differ across phases.

Regarding the control variables, we identify general CO_2 emissions and emissions intensity reductions in phase I and II that are not due to the ETS (however, the significance levels depend on the specification). Moreover, we still see a tendency that plants that entered the ETS in phase III had slightly higher emissions and emissions intensities than plants that entered in earlier phases, and that plants regulated by the ETS have higher emissions and emissions intensities than plants never regulated by the ETS. We identify negative and significant (at the 1 percent level) effects of relative energy prices on CO_2 emissions and emissions intensity in columns (1)-(2). The estimates are about -0.3 for both variables, implying that a 10 percent increase in relative energy prices is estimated to decrease CO_2 emissions and emissions intensity by 3 percent. In the model with plant fixed effects in columns (3)-(4), the estimated effect on emissions intensity drop (in absolute value) to -0.03, significant at the 10 percent level, whereas the estimated effect on emissions (0.02) is not significant. Finally, a 10 percent increase in the number of employees is estimated to increase CO_2 emissions by 6.2-8.9 percent (significant at the 1 percent level in both specifications). The effect of an increase in the number of employees on CO_2 emissions intensity is negative and significant in the basic specification, suggesting scale effects. However, this effect is no longer there in the specification that includes plant specific effects.

We also perform a number of robustness tests for which we do not provide tables. We replicate the results of Tables 5 and 7 using the alternative measure of emissions intensity mentioned in Section 3.1 – emissions relative to electricity use. The results are largely confirmed and the estimated coefficients and the corresponding p-values are similar to those reported in Tables 5 and 7. Next, we replicate Tables 4-7 on a sample with 1:3 nearest neighbor matching rather than 1:10. Again, the estimated coefficients and the corresponding p-values are very similar to those reported in Tables 4-7.

Finally, we replicate Tables 4-7 on a sample of treated and non-treated plants that are matched at the 3-digit industry level (rather than at the 2-digit level as in our main model). The estimated effects of phase II on emissions and emissions intensities (Tables 4-5 and 7) are no longer significant at conventional levels. This is possibly related to the drop in number of plant-year observations from 1,567 to 1,134. However, the estimated effects of phase II on economic performance still hold. We identify significant positive effects on value added and productivity in phase II across all specifications. The effects of phase II on value added lie in the range 31-32 percent, whereas the effect on productivity lie in the range 28-30 percent.

Table 7: Effects on CO_2 emissions and emissions intensity

Response variable:	Coef.	(1) Log of CO_2 Est.	(2) Log of CO_2 int. Est.	(3) Log of CO_2 Est.	(4) Log of CO_2 int. Est.
Treatment Phase I	β_1	.20	.23	.05	.07
		(.14)	*(.14)*	*(.10)*	*(.10)*
Treatment Phase II	β_2	-.19	-.14	-.26	-.22
		(.18)	*(.18)*	*(.14)*	*(.13)*
Treatment Phase III	β_3	-.08	-.06	-.01	.02
		(.29)	*(.30)*	*(.22)*	*(.22)*
Time dummy Phase I	π_1	-.28**	-.20*	-.20*	-.11
		(.11)	*(.11)*	*(.10)*	*(.10)*
Time dummy Phase II	π_2	-.36**	-.24*	-.14	-.10
		(.13)	*(.13)*	*(.12)*	*(.13)*
Time dummy Phase III	π_3	-.09	-.04	-.20	-.12
		(.26)	*(.27)*	*(.22)*	*(.22)*
Group fixed effect Phase I	γ_1	3.07***	3.03***		
		(.42)	*(.41)*		
Group fixed effect Phase II	γ_2	2.76***	2.80***		
		(.54)	*(.55)*		
Group fixed effect Phase III	γ_3	3.33***	3.34***		
		(.51)	*(.52)*		
Log of relative energy prices		-.30***	-.30***	-.02	-.03*
		(.09)	*(.09)*	*(.02)*	*(.02)*
Log of number of employees		.62***	-.39**	.89***	.01
		(.17)	*(.17)*	*(.18)*	*(.12)*
Plant specific effects	ν_i	No	Yes	No	Yes
Plant specific control variables		Yes	Yes	Yes	Yes
Industry dummies		Yes	Yes	Yes	Yes
Number of plant-year obs.		1,352	1,348	1,352	1,348
Number of plants		143	143	143	143
Equation number		(1)	(1)	(2)	(2)

Notes: *** $p < 0.01$, **$p < 0.05$, * $p < 0.1$. Robust standard errors in parentheses. Treatment plants are matched to control plants based on predetermined values of CO_2 emissions, number of employees, and exact matching on industries at the 2-digit level. Columns (1)-(2) are simple DID estimations with additional control variables. Columns (3)-(4) are panel data regression with plant fixed effects and additional control variables.

Tests of hypotheses:

	(1)	(2)	(3)	(4)
One-sided test of no effect in any phase:	p-value	p-value	p-value	p-value
$H_o: \min(\beta_1, \beta_2, \beta_3) \geq 0$	.38	.48	.14	.21
Wald test of equality of coefficients:				
$H_o: \beta_1 = \beta_2 = \beta_3$	.11	.14	.03	.04

5 Conclusions

In this paper we have examined impacts on Norwegian plants of the EU Emissions Trading System for the years 2005-2013, using micro-data at the plant level. We have found somewhat mixed results, both with respect to emissions and economic performance.

Our estimation results suggest that the ETS may have led to significant emissions reductions in the second phase (2008-12). However, we do not find any significant effects in the first phase (2005-7) or the third phase (2013). Nor can we reject the joint hypothesis test of no effect in any phase. Moreover, the results do not hold in the robustness test where we match at a more detailed industry level. Thus, the emission reduction found in phase II should be interpreted with caution. Moreover, when we estimate the effects on emissions intensities, we find no significant effects in any of the phases.

The limited effects on emissions and emissions intensity in our estimations can possibly be explained by the fact that the manufacturing industries have received close to a 100 percent of the quotas they need to cover their business-as-usual emissions. Surplus quotas could in principle have been sold to other plants, but the substantial allocation of quotas in the EU ETS (and other factors such as the financial crisis) have led to low quota prices. Thus the incentives for emissions reductions have been small throughout most of the period of EU ETS. When it comes to phase I, Norway was not formally linked to the EU ETS, and it may be questioned whether there was any binding cap on emissions for most Norwegian plants in this phase. Finally, the quota price was on average higher in the second phase than in the beginning of the third phase, which may explain why we find significant emissions reductions of phase II but not of phase III.

Our results further suggest that the ETS led to significantly higher value added and productivity in phase II. These findings are related to the fact that plants on average receive close to 100 percent of the allowances they need for free. If all allowances were instead auctioned by the government, the plants' costs would have been higher and thus value added and productivity lower. Furthermore, the plants may have been able to pass on (parts of) the increased marginal costs to the consumers, and hence increase their revenues through higher output prices. Finally, we notice that increased productivity due to environmental regulation is also consistent with the Porter Hypothesis.

We find no significant changes in the two other phases on neither productivity nor value added, although the estimates are consistently positive. The explanation for finding positive and significant impacts on economic performance only in phase II could be that the quota price facing Norwegian plants was highest in this phase. Hence, the mechanisms described in the previous paragraph were likely strongest in the second phase. The extent of allocation to manufacturing plants have not changed substantially between the phases.

In our study we control for phase time specific effects. However, it is possible that treated plants were differently affected by e.g. the financial crisis if they were more or less trade exposed than the control group. To our knowledge, empirical studies on the effects of the ETS on plants' or firms' emissions so far rely on matching methods in combination with difference-in-differences strategies. However, differences between regulated and unregulated plants might not be fully accounted for. As the regulator selects plants for participation in the ETS based on the capacity limit (e.g., total thermal effect or tons of products), regression discontinuity constitutes a suitable method for estimating the effects of the ETS. For further analysis on larger data sets, regression discontinuity methods should be considered.

From a policy perspective, our results do not give clear conclusions with regard to whether emissions trading lead to lower emissions. As emissions trading is a quantity instrument, it should in theory lead to emissions reductions if the cap is set below the unregulated emissions level. However, in our study we have only looked at Norwegian plants, and not all European plants regulated by the EU ETS. Moreover, since plants are allowed to bank allowances to the next phase, and also buy offsets from the Clean Development Mechanism (CDM), it is far from obvious how much overall emissions are reduced within a given phase.

Our results also suggest that Norwegian plants on average would not be negatively affected by the ETS even if more of the allowances were auctioned instead of given away for free to the plants. Free allocation of allowances is mainly motivated by the risk of carbon leakage. However, Martin et al. (2014) show that the current allocation in the EU ETS results in "substantial overcompensation for given carbon leakage risk". As allocation rules are determined at the EU level (also for the non-EU member Norway), the Norwegian authorities are not in a position to adjust the allocation. Nevertheless, our results should be relevant when considering the extent of allocation, both at the EU level and more generally.

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