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The Effect of EU ETS on Firm Productivity and Innovation-related Activity

Abstract

This study examines the impact of the EU Emission Trading System on firms' productivity and innovation behavior in the Finnish energy-intensive sector. Using unique administrative data on emissions and firm characteristics from 2000 onwards, the effect of the ETS is analyzed using staggered difference-in-difference design. The results show that while firms do not increase productivity or innovation inputs, those regulated are significantly more likely to introduce both process and product innovations. Additional findings suggest that the ETS effectively reduced energy intensity. Together the findings suggest that carbon pricing may stimulate technological adaptation and environmental improvements without generating measurable losses in productivity.

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Tiivistelmä

Päästökaupan vaikutukset yritysten tuottavuuteen ja innovaatioihin

Tämä tutkimus tarkastelee Euroopan unionin päästökauppajärjestelmän (EU ETS) vaikutuksia energiaintensiivisten yritysten tuottavuuteen ja innovaatiotoimintaan Suomessa. Tutkimuksessa hyödynnetään rekisteritietoja yritysten päästöistä ja muista taustamuuttujista vuodesta 2000 alkaen. Päästökaupan vaikutuksia arvioidaan ns. staggered difference-in-differences -menetelmään (staggered DiD) perustuvalla tutkimusasetelmalla. Tulokset osoittavat, että vaikka päästökauppa ei lisää yritysten tuottavuutta eikä innovaatiopanoksia, sääntelyn piirissä olevat yritykset kuitenkin lisäävät merkittävästi sekä prosessi- että tuoteinnovaatioita. Lisätarkastelut osoittavat, että päästökauppajärjestelmä vähentää tehokkaasti myös yritysten energiaintensiteettiä. Tulokset siis osoittavat, että hiilen hinnoittelu voi samanaikaisesti edistää teknologista sopeutumista ja vähentää negatiivisia ympäristövaikutuksia ilman havaittavia tuottavuustappioita.

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Keywords: EU ETS, Innovation, Productivity

Asiasanat: EU:n päästökauppa, Innovaatiot, Tuottavuus

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1. Introduction

Climate change has increased the importance of environmental policies designed to reduce greenhouse gas emissions while maintaining economic competitiveness. Among these policies, carbon pricing has become a central instrument because it provides firms with incentives to internalize the environmental costs of production and adopt cleaner technologies. The European Union Emissions Trading System (EU ETS), introduced in 2005, is the world's first large-scale multinational emissions trading scheme and remains the cornerstone of European climate policy. Covering energy-intensive industries and power generation, the system affects thousands of installations and approximately 40% of greenhouse gas emissions within the European Economic Area (European Commission, 2024).

Despite the growing use of carbon pricing, its consequences for firm performance remain debated. Traditional economic arguments emphasize the compliance costs associated with environmental regulation and predict adverse effects on firms' competitiveness and productivity. In contrast, the Porter Hypothesis (Porter, 1991; Porter and van der Linde, 1995) argues that well-designed environmental regulations may stimulate innovation and technological upgrading, potentially offsetting compliance costs and improving economic performance. This perspective has generated a large empirical literature examining whether environmental regulation can simultaneously improve environmental and economic outcomes.

The empirical evidence remains mixed. A substantial body of research finds little systematic relationship between environmental regulation and productivity growth, while other studies document positive effects for specific policies and sectors (e.g., Kozluk and Zipperer, 2014; Albrizio et al., 2017; Cohen and Tubb, 2017; Dechezleprêtre et al., 2019). Evidence on carbon pricing and the EU ETS is similarly inconclusive. Some studies report improvements in productivity and economic performance among regulated firms (Lutz, 2016; ; Marin et al., 2018; Klemetsen et al., 2020), whereas others find mostly statistically insignificant effects (e.g., Joltreau and Sommerfeld, 2019; Löschel et al., 2019). In contrast, the evidence regarding innovation is generally more positive. Existing studies suggest that carbon pricing can stimulate technological change, mostly increasing patenting or R&D expenditure (Calel and Deschezleprétre, 2016; Calel, 2020; Venmans et al., 2020).

However, important gaps remain in the literature. Most studies focus on a single measure of innovation, such as patents or R&D expenditures, even though innovation is a multi-stage process involving both innovation inputs and innovation outputs. As a result, relatively little is known about how carbon pricing affects different dimensions of innovation simultaneously, or how innovation responses translate into broader measures of firm performance such as productivity and investment. Second, little is known about whether carbon pricing affects firms' production processes, the development of new products, or both. Focusing on process and product innovation is important because environmental regulation may primarily induce technological upgrading of production processes, while effects on product innovation provide evidence on whether regulation stimulates or crowds out broader innovative activity. In addition, empirical evidence on the third phase of the EU ETS remains limited despite substantial reforms to the system. Teixidó et al. (2019), who review the empirical literature on the relationship between the EU ETS and technological change, also highlight the limited econometric evidence for Phase III implemented in 2013.

This paper examines the effect of the EU ETS on firm productivity and innovation-related activity in Finnish energy-intensive industries. The analysis distinguishes between innovation inputs, measured by R&D expenditure and the share of STEM workers, and innovation outputs, measured by process and product innovations. In addition, I investigate firms' investment behaviour and environmental performance through changes in carbon intensity, energy intensity, and energy use. By jointly analysing these outcomes, the paper provides a comprehensive assessment of how carbon pricing influences firms' adjustment strategies and long-run competitiveness.

The analysis combines several administrative datasets from Statistics Finland covering the period 2000–2020. The data include firm-level financial statements, greenhouse gas emissions, energy expenditures, innovation surveys, and R&D surveys. These sources are linked using unique firm identifiers, producing a rich panel of Finnish firms operating in energy-intensive industries. To identify the causal effects of the EU ETS, I exploit the staggered introduction of regulation across firms and estimate treatment effects using the difference-in-differences framework of Callaway and Sant'Anna (2021).

The results provide mixed evidence on the effects of EU ETS. I find no statistically significant effects of the EU ETS on productivity, investment intensity, or R&D expenditure. The regulation is associated with a decline in the share of STEM workers, suggesting that firms do not respond by increasing innovation inputs. Nevertheless, regulated firms are significantly more likely to introduce both process and product innovations. The increase in process innovation is consistent with firms adapting their production technologies in response to carbon pricing, while the positive effect on product innovation suggests that innovative activity was not confined solely to environmental compliance. The environmental results further indicate that the EU ETS reduced firms' energy intensity, although its effects on carbon intensity are limited. Taken together, these findings suggest that carbon pricing stimulated technological adaptation and environmental improvements without generating measurable gains or losses in productivity.

The paper is organized as follows. Section 2 provides an overview of the relevant empirical literature on the effects of environmental regulations on innovation and productivity growth. Section 3 describes the EU ETS and the institutional setting. Section 4 presents the unique matched administrative data and empirical methodology. Section 5 reports the results with various robustness tests. Section 6 discusses the findings and Section 7 concludes.

2. Related Literature

Based on neoclassical theory, environmental regulations are often viewed as imposing additional burdens on firms, thereby adversely affecting their competitiveness (Walley and Whitehead, 1994; Palmer et al., 1995). The theoretical framework is often centered on the Porter Hypothesis, which challenges this conventional view by arguing that well-designed environmental regulations can lead to Pareto improvements, implying that environmental performance can be enhanced without compromising economic performance (Porter, 1991; Porter and Linde, 1995). Such outcomes may arise through firms' investments in environmentally friendly technologies.

Empirical studies examining the Porter Hypothesis are typically categorized into two main strands: those investigating the consequences of the "strong" version of the hypothesis for competitiveness, such as productivity growth, and those focusing on innovation outcomes under the “weak” version. Numerous studies have relied on aggregated data at the economy or industry level to explore the relationship between environmental regulation and economic performance. However, given the focus of this paper on detailed administrative data at the firm level, I mostly concentrate on the literature most relevant to this setting.

To date, the empirical literature has not reached a consensus regarding the “strong” version of the Porter Hypothesis. Cohen and Tubb (2018) conduct a comprehensive meta-analysis of the relationship between environmental regulation and firm-level productivity or competitiveness, finding a statistically insignificant elasticity of productivity with respect to environmental regulation based on 16 studies. Similarly, Kozluk and Zipperer (2014) review empirical evidence on environmental policies and report ambiguous effects on productivity. Dechezleprêtre et al. (2019) survey the empirical literature using firm-level data on economic and environmental performance. A detailed examination of studies focusing on productivity (e.g., labor productivity or total factor productivity) reveals substantial heterogeneity, with some studies reporting negative, nonlinear, or zero effects.

Albrizio et al. (2017) employ an environmental policy stringency index to examine the impact of environmental policy on productivity growth. Their firm-level results for OECD countries suggest that the most productive firms benefit from environmental policy, while less productive firms experience a slowdown in productivity growth. Finally, Martin et al. (2014) analyze the causal effect of the carbon tax on UK manufacturing plants (the Climate Change Levy). Exploiting exogenous variation in eligibility for a tax discount—under which some plants paid only 20% of the tax—they find that the carbon tax reduced energy intensity and energy use, but had no statistically significant effects on other performance measures such as employment and revenues.

There are several studies that have specifically examined the effects of carbon pricing on firm-level productivity. Marin et al. (2018) find that the EU ETS had a positive effect on firms' labor productivity during both the first and second phases of the compliance periods. In contrast, Lutz (2016) documents a positive effect on productivity during the first compliance period, whereas Klemetsen et al. (2020) find that productivity increased after the second phase of the EU ETS, implemented in 2008. Löschel et al. (2019), however, document no statistically significant effect on economic performance, measured by the distance to the stochastic production frontier. Their subsample analysis, however, shows that the efficiency of treated firms increases in certain regulated industries. Venmans et al. (2020) examine the effects of carbon pricing on various measures of competitiveness using data from OECD and G20 countries and generally find statistically insignificant or positive effects on labor productivity and total factor productivity (TFP).[1]

The literature on the "weak" version of the Porter Hypothesis is more limited but includes several important contributions. Venmans et al. (2020) document an increase in patenting as a result of carbon pricing in OECD and G20 countries. Kozluk and Zipperer (2014) show that, while environmental policies have ambiguous effects on productivity, they are associated with relatively strong increases in environmental R&D. Hamamoto (2006) examines the effects of environmental regulation, proxied by pollution control expenditures,

[1] Other firm-level metrics have further been studies, showing that EU ETS has insignificant effect on competitiveness (Joltreau and Sommerfeld, 2019; Verde, 2020), but it has improved environmental performance (Petrick and Wagner, 2014; Wagner, et al., 2014; Jaraité and Di Maria, 2016), and increased gross output and exporting (Petrick and Wagner, 2014), value added (Klemetsen et al., 2020), and revenues and fixed assets (Dechezleprête, Nachtigall and Venmans, 2023).

in Japanese manufacturing industries and finds that regulation-induced increases in R&D investment have a positive effect on total factor productivity (TFP).

Calel and Dechezleprêtre (2016) use a European cross-country panel of installations and show that the pilot phase of the EU ETS increased low-carbon patenting. Interestingly, the system also encouraged regulated firms to increase their non-low-carbon patent filings, suggesting that the EU ETS did not crowd out other types of innovation. Teixidó et al. (2019) review the empirical literature on the relationship between the EU ETS and technological change, covering both econometric and non-econometric studies. Their main conclusion is that the EU ETS may stimulate innovation in low-carbon technologies rather than adopting existing resources, although free allowance allocation appears to have weakened these effects during the initial phases of the system. They also highlight the limited econometric evidence for Phase III. Calel (2020) focuses on a panel of firms in the UK and shows novel evidence on the European carbon market increasing innovation, as measured by patents and R&D expenditure, while showing limited effects on adopting "off-the-shelf" technologies.

Regarding investment responses to the EU ETS, Jaraitė and Di Maria (2016) and Marin et al. (2018) document positive effects on investment, whereas Bremer and Sommer (2025) find no statistically significant impact on firms' investment behavior across both the more generous Phases I and II and the more stringent Phase III.

Overall, the existing evidence suggests that carbon pricing tends to stimulate innovation and, in some cases, productivity; however, the effects remain heterogeneous across firms, contexts, and different phases of the EU ETS.

3. EU ETS policy

The European Union Emissions Trading System (EU ETS), introduced in 2005, constitutes the central instrument of the European Union's climate policy. Designed as a market-based mechanism, the system aims to reduce greenhouse gas emissions in a cost-effective manner by establishing a price for carbon emissions. It is widely regarded as the first large-scale international emissions trading scheme and remains one of the most extensive carbon markets globally, together with China's own emissions trading system in 2021. EU ETS covers all 27 European Union member countries and Liechtenstein, Iceland and Norway (EEA), having around 10,000 installations from energy-intensive industries and power generation, and constituting approximately 40% of EU's greenhouse gas emissions (European Commission, 2024). Based on statistics from the Energy authority in Finland, between 500 and 600 installations are included in the EU ETS annually, having 513 plants from 146 firms in 2024.

The EU ETS operates under a cap-and-trade framework. A cap is set on the total amount of emissions allowed within the system, and emission allowances—each corresponding to one ton of carbon dioxide—are either allocated to firms or auctioned. Regulated installations are required to surrender allowances equal to their verified emissions annually. Firms that reduce emissions below their allocated level can sell surplus allowances, while those exceeding their allocation must purchase additional permits. This structure creates financial incentives for emissions reduction and promotes the adoption of cleaner production technologies (European Commission, 2024).

Participation in the EU ETS is determined at the installation level rather than at the firm level. This implies that a single firm may operate both regulated and unregulated units, depending on whether specific capacity thresholds are exceeded. For instance, combustion plants with a rated thermal input above 20 megawatts (MW) are included in the system, alongside installations in sectors such as refining, metals, chemicals, and pulp and paper production.

Since its inception, the EU Emissions Trading System has undergone several phases, each reflecting policy learning and adjustments to economic conditions. The first phase (2005–2007) functioned as a pilot period, allowing policymakers and firms to gain experience with emissions trading. However, this phase was characterized by substantial over-allocation of allowances, which led to a collapse in carbon prices and limited incentives for emissions reduction (Ellerman and Buchner, 2007; Calel and Dechezleprêtre, 2016).

The second phase (2008–2012) coincided with the Kyoto Protocol commitment period and introduced more stringent emissions caps. Nevertheless, the global financial crisis significantly reduced industrial activity and emissions, contributing to a persistent surplus of allowances. This surplus continued to suppress carbon prices, weakening the effectiveness of the system.

In response to these challenges, the third phase (2013–2020) introduced more fundamental reforms. Allocation procedures became increasingly centralized at the EU level, and auctioning gradually replaced free allocation as the primary method of distributing allowances. Benchmarking based on the performance of the most efficient installations was also introduced for sectors still receiving free allowances. More recent reforms, including the establishment of the Market Stability Reserve, aimed to address the structural surplus of allowances and stabilize carbon prices. These changes have contributed to a significant increase in allowance prices in recent years.

A defining feature of the EU ETS, particularly in its early phases, has been the extensive use of free allocation of emission allowances. Under this system, firms received allowances based on historical emissions or sector-specific benchmarks. While this approach was intended to ease the transition to carbon pricing and mitigate concerns about competitiveness, it also had important implications for the system's economic effects. Empirical evidence suggests that many firms received allowances in excess of their actual emissions, especially during the initial phases of the EU ETS. As a result, firms were often not required to purchase additional permits and, in some cases, were able to generate revenue by selling surplus allowances. This over-allocation contributed to low carbon prices and reduced the direct cost burden of the policy.

The prevalence of free allocation has been identified as a key factor explaining why the EU ETS has not significantly affected firm competitiveness. By limiting firms' exposure to carbon costs, the system effectively mitigated potential negative impacts on production, employment, and profitability. At the same time, the opportunity cost of holding allowances still provided some incentives for emissions reduction, although these incentives were weaker than under a fully auction-based system.

4. Methods

4.1. Data sources

Several administrative datasets obtained from Statistics Finland are combined to study the effect of EU ETS on firms' productivity and innovation activity. The foundation of the analysis is the Financial Statement panel, which provides information on income statements and balance sheets at the firm level for the period from 2000 to 2023. The panel offers comprehensive coverage of independent business enterprises operating in various industries. All enterprises with at least 20 employees are directly included in the data, while information for smaller enterprises is derived from administrative records, such as business taxation registers. The data include variables such as the number of personnel (in full-time equivalents), industry code, value added, additions in equipment machinery and buildings, and sales.

Unique firm identification codes were used to link the Financial Statement panel to other administrative information on firm-level characteristics. Specifically, Statistics Finland's National Greenhouse Gas Inventory[2] includes larger emitting units that are representative of the entire Finnish manufacturing sector. This inventory provides annual GHG emissions and removals, which serves as an information base for climate policy planning and monitoring. The data comprise carbon dioxide and GHG emissions in CO_2 equivalents for the years 1999 to 2019 both at installation (establishment) and account holder (firm) level. Firms may have several regulated establishments. Single units may also have emissions from activities covered by the EU ETS (e.g., large boilers, kilns and power units) and emissions from activities not covered by the ETS (e.g., smaller boilers, vehicles, process emissions below

[2] Information on the Greenhouse Gas Inventory: https://www.tilastokeskus.fi/tup/khkinv/index_en.html

thresholds etc.). Importantly to our analysis, the data include installations that at some points are part of the EU ETS, and unregulated installations. After matching emissions data to other firm-level records, approximately 5.7% of firm-year observations are excluded due to misclassified firm identification codes or missing values. The data include a total of 1,001 firms, of which 286 firms are covered by the EU ETS.

Second, I obtained data on energy costs - disaggregated into electricity, fuel and heat expenditures - from the Longitudinal Database on Plants in Finnish Manufacturing, which is the third source of data. These data were also used to collect information on external R&D expenses and revenues from patents and licenses, the latter that is used as an alternative outcome variable for innovation-related activity. I have also used administrative FOLK registers from Statistics Finland, which cover the entire Finnish population from 1999 onwards. Most importantly to the analysis, the data provide comprehensive information on the occupation and educational background of the employees, that can be linked to their employing enterprises. This information is used to determine the number of STEM workers of a firm.

Finally, the analysis uses data from surveys. Information on the internal R&D expenses come from the R&D survey that is available at the firm level from 2000 to 2023. The R&D surveys are targeted primarily at larger firms (more than 100 employees) that are most likely to conduct R&D. The sample size totals approximately 4,000 firms per year, and the response rate of the survey is high (nearly 80%). Innovation survey, in contrast, includes information on whether a firm has implemented new processes or product innovations, and this information is available every second year from 2000 onwards, encompassing approximately 2,500 firms per year.

4.2. Regulated firms and sample construction

Emission data are used to identify regulated firms based on records of emissions from activities covered by the EU ETS. Firms covered during the pilot phase (2005-2007) are identified as those with ETS-covered emissions recorded by 2007. The number of such firms is 211, predominantly in the energy sector. Firms additionally included in Phase II (2008-2012) are identified as those with zero ETS-covered emissions prior to 2008 but positive emissions by 2012. Similarly, firms included in Phase III are defined as those with zero ETS-covered emissions prior to 2013 but positive emissions thereafter. The number of firms included in the second and third phases is substantially lower, at 34 and 41 firms, respectively. While a total of 286 firms are observed in the EU ETS over the period 2005–2019, the number of regulated firms varies across years due to staggered inclusion across phases, as well as firm exit and other changes in regulatory coverage. The annual number of regulated firms are consistent with statistics reported by the Energy Authority of Finland.[3]

The analysis focuses on firms operating in two-digit industries in which treated, regulated firms under the EU ETS are observed. In Finland, EU ETS firms are primarily concentrated in energy-intensive sectors. A small number of regulated firms (22) operate in sectors outside the scope of this study and are therefore excluded, also partly due to data limitations. Firms are classified according to the Statistical Classification of Economic Activities in the European Community (NACE), a standard classification system used in the EU. The final sample includes firms operating in subsectors 15 (manufacture of food products and beverages), 20 (manufacture of wood products), 21 (manufacture of pulp, paper and paper products), 24 (manufacture of chemicals and chemical products), 26 (manufacture of other

[3] For more information and statistics, please visit: https://energiavirasto.fi/en/frontpage.

non-metallic mineral products), 27 (manufacture of basic metals), and 40 (electricity, gas, steam, and hot water supply).

The final dataset is cleaned for missing values and outliers. In addition, common support is imposed on all baseline covariates, namely, the number of full-time equivalent employees, total factor productivity (TFP), energy costs, pre-treatment innovation activity, and aggregated industry classification, between treated and control firms, with all variables measured in the baseline year 2000.[4] In the absence of comprehensive register data on innovation outputs (such as patents), I proxy pre-treatment innovation capacity using R&D expenditures and the share of STEM workers, both measured in 2000. The choice of 2000 as the baseline year is motivated by the announcement of the EU ETS in 2001 and thereofe the risk of introducing bias due to firms' anticipation effect is minimal. Under these restrictions, the final sample includes approximately 110 -120 regulated firms per year, representing around 70% of all EU ETS-regulated firms in Finland.

4.3. Measures of firm-level outcomes

The objective of this study is to examine the effects of the EU ETS on firms' productivity and innovation-related activity, including both innovation inputs and outputs, and investments. These are captured by six outcome variables: (1) labor productivity, (2) R&D

[4] Baseline GHG levels are not included as a covariate for two reasons. First, they are highly correlated with energy costs and are therefore excluded to avoid overcontrolling. Second, emissions data are not available for all firms in 2000, which would reduce the sample size, particularly for the later phases of the EU ETS. Nevertheless, the results are robust to replacing energy costs in 2000 with initial GHG levels (measured over the period 2000–2019) as a covariate; these results are available upon request.

expenditures, (3) the share of STEM workers, (4) process innovation, (5) product innovation, and (6) investment intensity. By jointly analyzing investment, productivity, and different innovation outputs, it becomes possible to distinguish between technological upgrading, efficiency improvements, and potential crowding-out effects, thereby offering a more comprehensive assessment of how environmental policy shapes firm-level adjustment and long-run competitiveness.

All variables including monetary values are deflated to 2015 prices using the cost-of-living index. Labor productivity is measured as the logarithm of ratio of value added (VA) to the number of employees (in full-time equivalents). External R&D expenditure captures firms' bought investment in research and development. R&D expenses (in euros) are scaled by firm sales to construct size-adjusted measure. The share of STEM employees (from total workforce) provides a direct measure of human resources devoted to innovation. STEM employees are defined as individuals with tertiary-level education in science, technology, engineering, or mathematics, based on ISCED classifications. Two additional innovation-related outcomes are constructed from the Innovation survey. Specifically, two binary variables are defined to indicate whether a firm has introduced (i) new process innovations and (ii) new product innovations. Finally, investment intensity is measured as additions to machinery, equipment, and buildings and structures relative to total assets in the previous financial year.

4.4. CS estimator

I study the effect of EU ETS regulation on firms' economic performance and innovation activity using a staggered-adoption difference-in-differences design. Let Y_{it} denote the outcome of firm *i* in year *t*, and let $G_i \in \{2005, 2008, 2013\}$ denote the first year in which firm *i* becomes regulated under the EU ETS, and $D_i = 1$ refers to never treated firms. In the main analysis, firms that never enter the EU ETS in year *t* constitute the control group for treated firms in that year. The empirical analysis is conducted using the Callaway and Sant'Anna (2021) estimator, which is appropriate in settings with treatment effect heterogeneity and staggered treatment timing.

The causal parameter of interest is the group-time average treatment effect:

$$ATT(g,t) = E[\, Y_{t(g)} - Y_{t(0)} \mid G_i = g \,], t \geq g$$

Here, $Y_{t(g)}$ denotes the firm's outcome in year *t* if the firm first becomes treated in year *g*, while $Y_{t(0)}$ denotes the corresponding untreated outcome. Thus, $ATT(g,t)$ measures the average treatment effect in year *t* for firms entering the EU ETS in cohort *g*. Identification relies on a conditional parallel trends assumption, under which, conditional on pre-treatment firm characteristics X_i, untreated outcomes would have followed the same average trend for treated and control firms. In the present application, X_i consists of firm size, total factor productivity, energy costs, innovation capacity and aggregated industry classification, measured in the initial year 2000. By fixing these covariates prior to the introduction of the EU ETS, I mitigate concerns related to post-treatment bias.

Formally, the identifying assumption is:

$$E[\, Y_{t(0)} - Y_{\{t-1\}(0)} \mid G_i = g, X_{i,2000} \,] = E[\, Y_{t(0)} - Y_{\{t-1\}(0)} \mid G_i \in C_t, X_{i,2000} \,], t \geq g$$

Where C_t denotes the set of firms that are untreated in year t (C_t: $D_i = 1$). To summarize the average impact of EU ETS regulation across all treatment cohorts and post-treatment periods, I compute the ATT:

$$ATT^{agg} = \sum_{g} \sum_{t \geq g} w(g,t) ATT(g,t)$$

where $w(g,t)$ denotes the aggregation weights. In addition, cohort-specific average effects are reported separately for the 2005, 2008, and 2013 treatment cohorts:

$$ATT_g^{phase} = \sum_{t \geq g} w_g(t)\ ATT(g,t)$$

for g $\in \{2005, 2008, 2013\}$. These phase-specific estimates allow the effect of the EU ETS on firm outcome to differ across regulatory phases. Finally, to examine the dynamic pattern of treatment effects and assess the plausibility of the identifying assumption, I also estimate an event-study specification. Let $l = t - G_i$ denote event time, that is, the number of years relative to the first year of EU ETS regulation. For each treated firm, event time $l = 0$ corresponds to the first treatment year, $l < 0$ denotes periods before the treatment (five years in thus study), and $l > 0$ denotes periods after the treatment (ten years). The dynamic treatment effect at event time l is defined as:

$$ATT^{es}(l) = E[Y_t(G_i) - Y_t(0) |\ t - G_i = l, G_i < \infty]$$

In practice, these effects are estimated by aggregating the cohort-specific group-time effects *ATT(g,t)* over observations sharing the same relative event time *l*. This yields a sequence of dynamic treatment effects tracing the evolution of innovation before and after EU ETS entry.

The event-study profile is particularly useful for testing whether pre-treatment effects are close to zero and for examining whether the treatment effect emerges immediately or only gradually after regulation begins.

5. Empirical findings

5.1. Descriptive statistics

Table 1 reports summary statistics for the main variables measured in 2000 separately for the control group and firms entering the EU ETS during Phases I (2005), II (2008), and III (2013). Several clear differences emerge between regulated and non-regulated firms. First, firms covered by the EU ETS are substantially larger than firms in the control group. Firms entering the system during the pilot phase report average sales of approximately 260 million euros and employ more than 540 workers on average, whereas firms in the control group have average sales of 45 million euros and approximately 148 employees. Firms entering during later phases are also considerably larger than non-regulated firms, although smaller than Phase I entrants.

Second, regulated firms are significantly more energy- and emission-intensive. Average GHG-levels among Phase I firms exceed 213,000 tons of CO2 equivalents, compared with approximately 5,600 tons in the control group. Similarly, energy expenditures are substantially higher among treated firms, particularly in the first treatment cohort. Third, regulated firms exhibit higher levels of innovation-related activity prior to treatment. Firms covered by the EU ETS report higher R&D expenditures and employ substantially more STEM workers than firms in the control group.

The industrial composition of treated firms also differs markedly from that of the control group. Most regulated firms operate in electricity and energy supply (NACE 40), pulp and paper production (NACE 21), chemicals (NACE 24), and basic metals (NACE 27), all of which are sectors characterized by high energy use and carbon emissions. In contrast, the control group is more broadly distributed across manufacturing industries. Overall, the descriptive statistics highlight substantial heterogeneity between regulated and non-regulated firms, particularly with respect to firm size, emissions, and energy use. These differences motivate the use of common support restrictions and conditioning on baseline firm characteristics in the empirical analysis.

[Add Table 1 in here]

5.2. Aggregate results

The results for the firms' productivity and innovation-related activity are reported in Table 2. Panel A reports the findings for the aggregate ATT of the EU ETS across all treated firms, assuming that there is no heterogeneity in the effects over time and between treatment groups (Phases I-III). Panel B of the same table reports the cohort-specific ATT estimates. All the results are based on a control group consisting of never-treated firms. The corresponding event-study estimates for the aggregated ATT are depicted in Figure 1, showing the coefficients for five years prior to and ten years following treatment.

Before presenting the main results, the validity of the parallel trends is first investigated. Figure 1 plots the pre-treatment coefficients, and this enables to visually inspect whether there are trends in the pre-treatment coefficients. While some pre-treatment coefficients deviate slightly from zero, there is no clear systematic trend, and most estimates are statistically insignificant. This provides support for the parallel trends assumption. In addition, as suggested by Callaway and Sant'Anna (2021), the Wald tests for the joint significance of the pre-treatment coefficients, along with their p-values, are reported at the bottom of the table. Importantly to the validity of the regression design, none of the tests reject the null hypothesis at conventional significance levels.

The aggregate ATT results indicate limited effects of the EU ETS on firms' innovation-related activity. As shown in Column (1) of Table 2, the EU ETS is associated with a reduction in labor productivity of approximately 4%, although the effect is not statistically significant. Similarly, external R&D intensity and investment intensity are not significantly affected by EU ETS regulation, as reported in Columns (2) and (6), respectively. While the estimated effects are negative, the CR estimators are not statistically significant.

However, I do find that the EU ETS leads to a reduction in firms' innovation inputs, as measured by the share of STEM workers in total employment. Specifically, the share of research employment decreases by 1.7 percentage points, with the effect being statistically significant at the 10% level (Column 3). Interestingly, although innovation inputs—measured by research personnel—appear to be negatively affected by the EU ETS in regulated firms, there is a positive effects on innovation outputs, namely process innovations. The estimated effect is sizable: EU ETS regulation increases the probability of process innovation by 0.25 percentage points (Column 4). Evaluated at the baseline mean of 0.51, this corresponds to an increase of approximately 50% in the probability of innovation. The ATT-CS estimator for product innovation is also positive but does not reach statistical significance at the conventional levels.

5.3. Group aggregation

The aggregate results may conceal important heterogeneity across different phases of EU ETS regulation. Panel B of Table 2 reports the effects separately for Phases I, II and III. The results for labor productivity, R&D intensity, and investments show statistically insignificant effects for each cohort. In contrast, the share of research personnel decreases following Phases I and Phase III (by 1.7-1.8 percentage points) but remains unaffected during Phase II (Column 3 of Panel B). Finally, both types of innovation outcomes are positively affected by the EU ETS, but only after its pilot phase (Columns 4 and 5). Specifically, Phase II regulation increases the probability of process innovation by 59 percentage points and product innovation by 56 percentage points, while in Phase III these probabilities increase by 71 and 33 percentage points, respectively.

5.4. Robustness tests

The baseline results are subjected to several robustness and sensitivity checks, including alternative variable definitions, estimation samples, and model specifications. First, I use an alternative control group in which both never-treated and not-yet-treated firms are included in the pool of potential controls. Not-yet-treated firms are those that become regulated in Phase II (serving as controls for firms joining the EU ETS in Phase I) or in Phase III (serving as controls for firms joining the EU ETS during Phases I and II). As reported in Table A1 in the Appendix, the results are broadly consistent with the baseline findings. In particular, the EU ETS decreases the share of STEM workers while increasing both process and product innovation. However, the aggregate effect on process innovation no longer reaches statistical significance at conventional levels in Column 4 of the table (CR: 0.199, p-value: 0.105)

Second, I use a larger sample of firms in the pool of potential controls. In the main specification, the control firms were selected from the sample observed in the emission data, whereas the revised control group is extended to include firms outside the emission data, provided that the common support condition holds. This broader control group therefore includes also non-emitting firms. As shown in Table A2 in the Appendix, the results remain largely unchanged. However, the results for process and product innovation are not statistically significant in Phase III. Note also that the Wald tests reject the null hypothesis of joint insignificance for investment and process innovation, indicating that these results should be interpreted with caution. Including low-emission firms in the control group introduces firms with structurally different innovation behavior and limited exposure to carbon regulation, which likely weakens the comparability between treated and control units and attenuates some of the estimated treatment effects. This divergence suggests that the parallel trends assumption is more credible when the control group is restricted to firms with similar emissions profiles.

Third, the control variables are measured in year *t-2* for each EU ETS cohort rather than in 2000. As Table 1 shows, the number of regulated firms drops when the sample is restricted to firms observed before the announcement of the environmental policy. Although this restriction may effectively reduce bias induced by anticipation effects, it excludes a substantial share of firms established after 2000. To address this issue, the control variables are instead measured at *t-2*, which increases the number of regulated firms in the analysis from 140 (Table 1) to 226. The results are presented in Table A3 in the Appendix. The results remain robust for the share of STEM workers, although the CR estimator is not statistically significant in Phase III (Column 3). EU ETS is also positively associated with product innovation in each cohort as well as over the entire policy period (Column 5). Specifically, the EU ETS increases the likelihood of introducing a new product innovations by, on average, 0.21 percentage points, corresponding to an approximately 43% relative to baseline mean of 0.490. However, the positive effect on process innovations disappears, and the Wald test rejects the null hypothesis of joint insignificance for process innovation. This suggests that the results for process innovation may be affected by anticipation effect.

Fourth, I employ alternative measures of innovation-related activity to further assess the sensitivity of the results. I begin by considering Olley–Pakes total factor productivity and an alternative measure of labor productivity defined as sales, rather than value added, per employee. The results, presented in Table A4 of the Appendix, are broadly consistent with the main findings and suggest that the EU ETS has no statistically significant effect on firm productivity (Columns 1 and 2). The actual number of STEM workers is also considered. The results suggest that the EU ETS reduces STEM employment by approximately 15%, or 0.5 full-time equivalent employees, evaluated at the sample mean of 3.3. However, this negative effect is observed only in Phase II. The final alternative measures are internal R&D intensity and patent revenue intensity, the latter serving as a proxy for patent activity. Data on internal R&D expenditures are obtained from the R&D Survey, while revenues from patents and licenses are drawn from the Longitudinal Database on Plants in Finnish Manufacturing. The CS estimators are reported in Columns 4 and 5 of Table A4. The point estimates for internal R&D intensity are not statistically different from zero, consistent with the corresponding results based on administrative data on external R&D expenditure. Similarly, the estimated relationship between EU ETS regulation and revenues from patents and licenses is not statistically significant at conventional levels in any phase.

5.5. *Effects on environmental performance*

As additional outcomes, Table 3 examines the impact of the EU ETS on firms' environmental outcomes, providing important benchmarks for assessing the broader implications of environmental regulation for firm performance. To measure environmental performance, I first consider two indicators: carbon intensity and energy intensity. Carbon intensity is defined as the ratio of a firm's total annual greenhouse gas (GHG) emissions to value added, while energy intensity is measured as total energy costs relative to value added. Examining the effects of the EU ETS on these measures is also relevant because changes in carbon and energy intensity may reflect technological improvements and other adjustments in firms' production processes.

Finally, I examine changes in firms' energy mix using two measures: the share of fuel costs in total energy costs (including electricity, fuel, and heat) and the share of fuel use in total energy consumption. Energy consumption (kWh) is estimated by dividing expenditures on fuels, electricity, and heat by their respective prices.

Panel A reports the aggregate average treatment effects on the treated (ATTs), while Panel B presents cohort-specific estimates for firms entering the EU ETS during Phases I, II, and III. Figure 2 complements these results by plotting the dynamic treatment effects, including both pre- and post-treatment coefficients with 95% confidence intervals. Overall, the pre-treatment coefficients do not exhibit a clear systematic pattern and are generally statistically insignificant, lending support to the plausibility of the parallel trends assumption.

As shown in Panel A of Table 3, the EU ETS is associated with a modest reduction in carbon intensity of less than 1%, although the estimate is not statistically significant. In contrast, the policy has a pronounced effect on firms' energy intensity. Specifically, energy intensity declines by approximately 10%, and the effect is both economically meaningful and statistically significant at the 1% level (Column 2). This finding suggests that regulated firms adjusted their energy use in response to carbon pricing, potentially through improvements in energy efficiency or shifts toward less energy-intensive production processes. By contrast, the aggregate CS estimates for the share of fuel costs and the share of fuel use are not statistically different from zero (Columns 3 and 4).

Panel B reports cohort-specific CS estimates, providing further insights into the timing and heterogeneity of these effects. The reduction in energy intensity is concentrated among firms entering the EU ETS during Phase I, for which the estimated decline is approximately 11%. Although the estimated effect for Phase III firms is larger in magnitude (CS estimate: −0.283), it is not statistically significant at conventional levels, indicating substantial heterogeneity in responses across cohorts.

Interestingly, regulated firms appear to have altered their energy mix during Phase II of the EU ETS. Both the share of fuel costs in total energy costs and the share of fuel use in total energy consumption increase by approximately 15%. Because the effect is observed for both expenditures and physical energy use, it is unlikely to be driven solely by relative energy price changes. Instead, the results suggest a substitution toward fuel-based energy inputs relative to electricity and heat.

This pattern is particularly noteworthy given the absence of corresponding changes in carbon intensity. One possible explanation relates to the institutional design of Phase II, during which most regulated installations received a substantial share of emission allowances free of charge. Combined with indirect effects of carbon pricing on electricity prices, these features may have encouraged firms to adjust their energy mix rather than undertake more substantial technological changes. However, because the analysis does not distinguish between different fuel types, the results should not be interpreted as evidence of a shift toward more carbon-intensive fuels. Rather, they indicate that the EU ETS influenced the composition of energy inputs used by regulated firms during Phase II.

6. Discussion

This paper examines the effects of EU ETS on firm-level productivity, innovation-related activity, investment, and environmental performance in Finnish energy-intensive industries. Using matched administrative data and a staggered-adoption difference-in-differences framework, the analysis follows firms before and across the three phases of the EU ETS between 2000 and 2020. Overall, the results provide mixed evidence. While the findings offer little evidence that the EU ETS improved firms' productivity, they indicate that the regulation increased innovation outputs and reduced energy intensity. Thus, the results are broadly consistent with the hypothesis according to which environmental regulation promotes innovation, but provide limited support for the environmental policy predicting improvements in productivity and competitiveness.

The results show that the EU ETS had no statistically significant effect on productivity. This finding is broadly consistent with the meta-analysis of Cohen and Tubb (2018) and the survey evidence reviewed by Kozluk and Zipperer (2014) and Dechezleprêtre et al. (2019), which emphasize the absence of a robust relationship between environmental regulation and productivity growth. In contrast, the results are not in line with studies focusing specifically on the EU ETS, such as Marin et al. (2018), Lutz (2016) and Klemetsen et al. (2020), which often report positive effects on firms' productivity. Note, however, that the absence of negative productivity effects suggests that the compliance costs associated with carbon pricing did not materially harm the competitiveness of regulated firms.

The most notable innovation-related finding is that the EU ETS increased both process innovation and product innovation. These results indicate that firms responded to carbon pricing not only through changes in production processes but also through the introduction of new or improved products. Although this finding suggests that carbon pricing did not crowd out broader innovative activity within firms (e.g., Calel and Dechezleprêtre, 2016), more work is needed to understand whether EU ETS increased non-environmental product innovations. At the same time, EU ETS reduced the share of STEM workers employed by regulated firms. One possible explanation is that firms substituted in-house research personnel with externally sourced R&D activities. However, this interpretation is not supported by the data, as external R&D expenditure does not increase following EU ETS regulation. Likewise, the findings show statistically insignificant effect on internal R&D expenditure. Taken together, these results suggest that the observed increase in innovation outputs is not driven by additional research effort, but rather relying on alternative adjustment mechanisms, such as the adoption of existing technologies or incremental process improvements. The positive effects on innovation outputs are consistent with previous evidence on the effects on EU ETS stimulating innovation activity (Calel and Dechezleprêtre, 2016; Teixidó et al., 2019; Calel, 2020). Accordingly, the statistically insignificant effect of the environmental policy on investments is in line with Bremer and Sommer (2025) but contrast with Jaraité and Di Maria (2016) and Marin et al. (2018).

The environmental results further reveal the mechanisms through which firms adjusted to carbon pricing. While carbon intensity shows little systematic response, energy intensity declines by approximately 10%, indicating that regulated firms became more energy efficient. This finding closely resembles the evidence reported by Martin et al. (2014), who show that the UK Climate Change Levy reduced energy use without substantially affecting other measures of firm performance. Likewise, studies focusing solely on EU ETS report improved environmental performance (Petrick and Wagner, 2014; Wagner, et al., 2014; Jaraité and Di Maria, 2016). The cohort-specific environmental results provide additional evidence on firms' adjustment mechanisms. In particular, firms entering the EU ETS during Phase II increased both the share of fuel costs and the share of fuel use in total energy consumption. The results suggest that regulated firms altered their energy mix by increasing their reliance on fuel-based energy inputs relative to electricity and heat. One possible explanation relates to the extensive free allocation of emission allowances and indirect electricity-price effects that characterized the second phase of the EU ETS.

7. Conclusions

The EU ETS represents one of the most important market-based instruments for reducing greenhouse gas emissions. While concerns have frequently been raised about its potential adverse effects on firm competitiveness, the findings of this study suggest that such concerns may be overstated in the Finnish context. Regulated firms do not experience significant reductions in productivity, investment, or R&D activity, while process and product innovations and energy efficiency improve following regulation.

These findings suggest that carbon pricing can stimulate technological adaptation and environmental improvements without imposing substantial costs on firm performance. Importantly, the results indicate that firms may respond through technology adoption, process improvements, and changes in energy use rather than through increased formal R&D investment. This highlights the importance of considering multiple dimensions of innovation when evaluating the effectiveness of environmental policy.

The analysis also points to several avenues for future research. In particular, the available data do not allow the identification of specific fuel types or technologies adopted by firms. A more detailed examination of these adjustment mechanisms together with potential outsourcing of services would improve our understanding of how carbon pricing influences firm behavior and environmental performance over the longer term.

References

Albrizio, S., Kozluk, T. and Zipperer, V., 2017. Environmental policies and productivity growth: Evidence across industries and firms. *Journal of Environmental Economics and Management* 81, 209-226.

Bremer, L., and Sommer, K. (2025). Economic performance and investments under emissions trading: Untangling the effects of a staggered regulation. *Energy Economics* 142, 108170.

Calel, R., 2020. Adopt or innovate: Understanding technological responses to cap-and-trade. *American Economic Journal: Economic Policy* 12, 170-201.

Calel, R. and Dechezleprêtre, A., 2016. Environmental policy and directed technological change: Evidence from the European carbon market. *The Review of Economics and Statistics* 98, 173-191.

Callaway, B. and Sant'Anna, P., 2021. Difference-in-difference with multiple time periods. *Journal of Econometrics* 225, 200-230.

Cohen, M.A. and Tubb, A., 2018. The impact of environmental regulation on firm and country competitiveness: a meta-analysis of the porter hypothesis. *Journal of the Association of Environmental and Resource Economists* 5(2), 371-399.

Dechezleprêtre, A., Koźluk, T., Kruse, T., Nachtigall, D. and De Serres, A., 2019. Do environmental and economic performance go together? A review of micro-level empirical evidence from the past decade or so. *International Review of Environmental and Resource Economics* 13(1-2), 1-118.

Dechezleprête, A., Nachtigall, D. and Venmans, F., 2023. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *Journal of Environmental Economics and Management* 118, 102758.

Ellerman, D. and Buchner, B. 2007. The European Union Emissions Trading Scheme: Origins, allocation, and early results. *Review of Environmental Economics and Policy*, 1(1), 66–87.

Hamamoto, M., 2006. Environmental regulation and the productivity of Japanese manufacturing industries. *Resource and Energy Economics* 28(4), 299-312.

Jaraité, J. and Di Maria, C., 2016. Did the EU ETS make a difference? An empirical assessment using Lithunian firm-level data. *Energy Journal* 37, 1-23.

Joltreau, E. and Sommerfeld, K., 2019. Why does emissions trading under the EU Emissions Trading System (ETS) not affect firms' competitiveness? Empirical findings from the literature. *Climate Policy* 19, 453-471.

Klemetsen, M., Rosendahl, K.E. and Jakobsen, A.L., 2020. The impacts of the EU ETS on Norwegian plants' environmental and economic performance. *Climate Change Economics* 11(01), 2050006.

Kozluk, T. and Zipperer, V., 2014. Environmental policies and productivity growth: A critical review of empirical findings. *OECD Journal: Economic Studies* 1, 155-158.

Lutz, B., 2016. Emissions Trading and Productivity: Firm-Level Evidence from German Manufacturing. ZEW - Centre for European Economic Research Discussion Paper No. 16-067, Available at SSRN: https://ssrn.com/abstract=2850541 or http://dx.doi.org/10.2139/ssrn.2850541

Löschel, A., Lutz, B. and Managi, S., 2019. The impacts of the EU ETS on efficiency and economic performance – An empirical analyses for German manufacturing firms. *Resource and Energy Economics* 56, 71-95.

Marin, G., Marino, M., and Pellegrin, C. (2018). The impact of the European Emission Trading Scheme on multiple measures of economic performance. *Environmental and Resource Economics* 71, 551-582.

Martin, R., Preux, L. and Wagner, U., 2014. The impact of a carbon tax on manufacturing: Evidence from microdata. *Journal of Public Economics* 117, 1-14.

Palmer, K., Oates, W. and Portrey, P., 1995. Tightening environmental standards: the benefit-cost or the no-cost paradigm? *Journal of Economic Perspectives* 9, 119-132.

Petrick, S. and Wagner, U., 2014. The impact of carbon trading on industry: Evidence from German manufacturing (RMS), Kiel Working paper, No. 1912.

Porter, M., 1991. Towards a dynamic theory of strategy. *Strategic Management Journal* 12, 95-117.

Porter, E. and van der Linde, C., 1995. Towards a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives* 9, 97-118.

Teixidó, J., Verde, S. and Nicolli, F., 2019. The impact of the EU Emission Trading System on low-carbon technological change: The empirical evidence. *Ecological Economics* 164, 106347

Venmans, F., Ellis, J. and Nachtigall, D., 2020. Carbon pricing and competitiveness: are they at odds? *Climate Policy* 20, 1070-1091.

Verde, S., 2020. The impact of the EU Emission Trading System on competitiveness and carbon leakage: The econometric evidence. *Journal of Economic Surveys* 34, 320-343.

Wagner, U.J., Muüls, Martin, R. and Colmer, J., 2014. The causal effect of the European Union Emissions Trading Scheme: Evidence from French Manufacturing plants.

Walley, N. and Whitehead, B., 1994. It’s not easy being green. Harvard Business Review 46-52.

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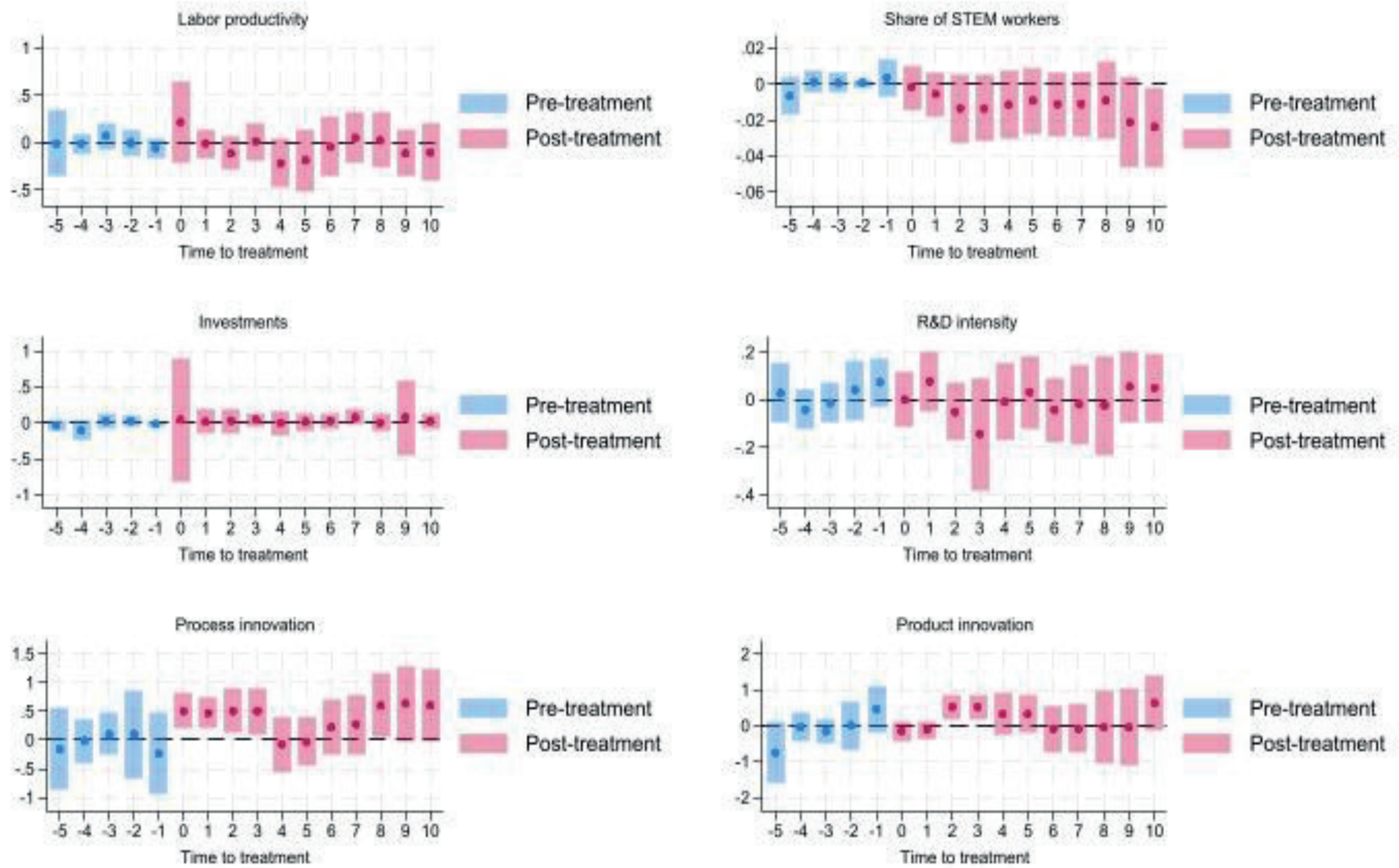

Figure 1: Aggregated event-study estimates on the effect of EU ETS on productivity and innovation-related activity

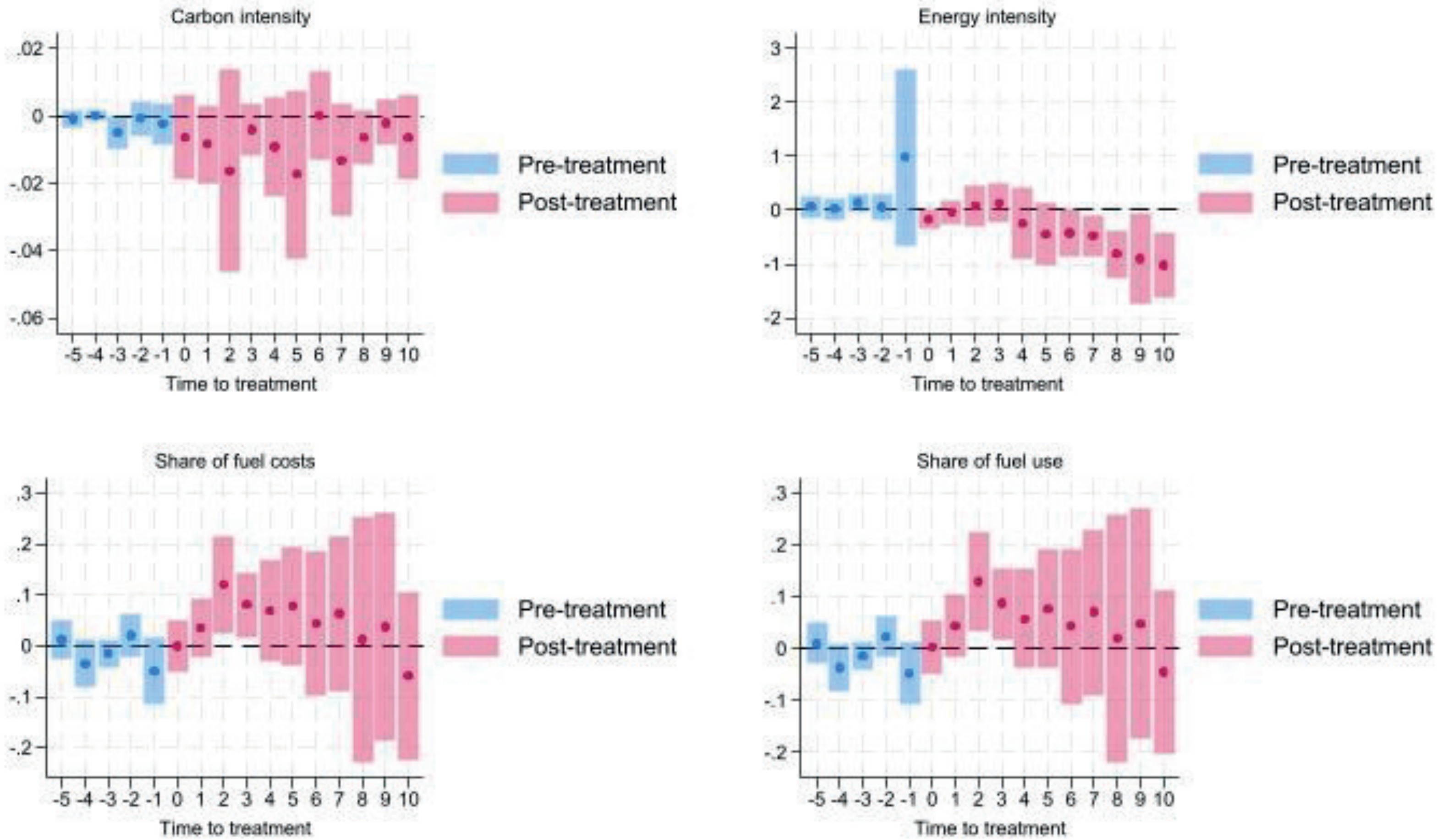

Figure 2: Aggregated event-study estimates on the effect of EU ETS on environmental performance

Table 1. Summary statistics of the variables

	Control group (1)	Treated 2005 (2)	Treated 2008 (3)	Treated 2013 (4)
Sales (M€)	45.2	260.2	117.07	129.13
Number of employees	147.69	543.14	182.11	229.98
Current ratio	1.97	2.00	1.83	2.02
Equity ratio	44.34	50.87	52.55	53.87
GHG level (tCO2e)	5575.21	213467.7	48031.03	17386.21
Energy costs (M€)	1.07	19.18	7.30	11.04
R&D costs (M€)	0.159	0.786	0.260	0.797
STEM employees (FTE)	3.01	18.39	9.94	8.28
Tol 15	0.189	0.046	0.169	-
Tol 20	0.143	0.066	0.214	0.202
Tol 21	0.029	0.164	-	-
Tol 24	0.195	0.031	0.085	0.202
Tol 26	0.090	0.071	-	-
Tol 27	0.102	0.026	0.073	0.202
Tol 40	0.252	0.595	0.460	0.394
N. of firm-year obs.	3,628	2,135	248	208
Number of firms	255	117	13	10

Notes: R&D intensity is measured as the external R&D expenditure over sales. Investments intensity is measured as additions to machinery, equipment and buildings over total assets. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level.

Table 2. CS estimators on the effect of EU ETS on firm's economic performance

	log(Labor productivity) (1)	R&D intensity (2)	Share of STEM workers (3)	Process innovation (4)	Product innovation (5)	Investment intensity (6)
Panel A: Overall aggregation						
Overall EU ETS	-0.039	-0.014	-0.017*	0.245*	0.165	0.033
	(0.1045)	(0.0589)	(0.0087)	(0.1323)	(0.1497)	(0.0584)
Panel B: Group aggregation						
C1: 2005	-0.068	-0.033	-0.018*	0.218	0.144	0.041
	(0.1127)	(0.0650)	(0.0098)	(0.1417)	(0.1630)	(0.0657)
C2: 2008	0.306	-0.022	-0.008	0.588**	0.556***	-0.043
	(0.3457)	(0.0397)	(0.0096)	(0.2877)	(0.1950)	(0.0675)
C3: 2013	-0.066	0.378	-0.018**	0.705**	0.334**	-0.002
	(0.1510)	(0.3242)	(0.0082)	(0.2806)	(0.1589)	(0.0386)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
N. of observations	5,903	6,093	6,077	2,208	2,208	6,174
Outcome mean	154,935	0.222	0.013	0.510	0.490	0.0914
Wald statistics	17.730	5.692	10.135	8.108	11.593	18.615
Wald p-value	0.2194	0.9737	0.7523	0.3232	0.1148	0.1802

Notes: R&D intensity is measured as the external R&D expenditure over sales. Investments intensity is measured as additions to machinery, equipment and buildings over total assets. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level. CS estimators using never-treated firms as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

Table 3. CS estimators on the effect of EU ETS on firm's environmental performance

	log(Carbon intensity) (1)	Log(Energy intensity) (2)	Share of fuel costs (3)	Share of fuel use (4)
Panel A: Overall aggregation				
Overall EU ETS	-0.007	-0.109***	0.027	0.034
	(0.0073)	(0.0379)	(0.0450)	(0.0431)
Panel B: Group aggregation				
C1: 2005	-0.008	-0.112***	0.023	0.030
	(0.0078)	(0.0409)	(0.0491)	(0.0470)
C2: 2008	0.002	0.018	0.153*	0.156*
	(0.0071)	(0.0559)	(0.0896)	(0.0903)
C3: 2013	0.018	-0.283	-0.082	-0.088
	(0.0183)	(0.2018)	(0.0934)	(0.0962)
Other controls	Yes	Yes	Yes	Yes
N. of observations	4,125	6,264	5,103	5,103
Outcome mean	0.002	0.119	0.426	0.465
Wald statistics	16.923	18.012	16.690	18.206
Wald p-value	0.2603	0.2062	0.2731	0.1976

Notes: Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level. CS estimators using never-treated firms as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

Appendix

Table A1. CS estimators on the effect of EU ETS on firm's economic performance: different control group

	log(Labor productivity) (1)	R&D intensity (2)	Share of STEM workers (3)	Process innovation (4)	Product innovation (5)	Investment intensity (6)
Panel A: Overall aggregation						
Overall EU ETS	-0.053	0.011	-0.016*	0.199	0.123	0.003
	(0.1035)	(0.0580)	(0.0081)	(0.1226)	(0.1267)	(0.0309)
Panel B: Group aggregation						
C1: 2005	-0.084	-0.005	-0.016**	0.166	0.103	0.008
	(0.1100)	(0.0621)	(0.0091)	(0.1322)	(0.1389)	(0.0301)
C2: 2008	0.300	-0.018	-0.008	0.601**	0.418*	-0.050
	(0.3447)	(0.0429)	(0.0094)	(0.2645)	(0.2317)	(0.0597)
C3: 2013	-0.066	0.378	-0.018**	0.705**	0.334**	-0.002
	(0.1510)	(0.3242)	(0.0082)	(0.2806)	(0.1589)	(0.0385)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
N. of observations	5,903	6,093	6,077	2,214	2,214	6,174
Outcome mean	11.349	0.222	0.013	0.510	0.490	0.0914
Wald statistics	14.170	8.235	12.524	9.525	12.333	17.133
Wald p-value	0.4371	0.8767	0.5643	0.2171	0.0901	0.2492

Notes: R&D intensity is measured as the external R&D expenditure over sales. Investments intensity is measured as additions to machinery, equipment and buildings over total assets. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level. CS estimators using both never-treated and not-yet-treated firms as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

Table A2. CS estimators on the effect of EU ETS on firm's economic performance: larger data set

	log(Labor productivity) (1)	R&D intensity (2)	Share of STEM workers (3)	Process innovation (4)	Product innovation (5)	Investment intensity (6)
Panel A: Overall aggregation						
Overall EU ETS	0.002	-0.027	-0.011*	0.016	0.020	-0.197
	(0.1174)	(0.0597)	(0.0063)	(0.1150)	(0.0966)	(0.3630)
Panel B: Group aggregation						
C1: 2005	-0.004	-0.049	-0.012	-0.028	-0.002	-0.223
	(0.1272)	(0.0648)	(0.0071)	(0.1212)	(0.1023)	(0.4151)
C2: 2008	0.075	-0.049	-0.006	0.751***	0.527***	-0.030
	(0.2862)	(0.0449)	(0.0076)	(0.1794)	(0.1843)	(0.0601)
C3: 2013	-0.013	0.450	-0.016*	0.436	0.024	0.017
	(0.1575)	(0.3504)	(0.0091)	(0.3641)	(0.2090)	(0.0404)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
N. of observations	68,599	73,976	72,382	5,075	5,075	72,303
Outcome mean	57,986	0.153	0.002	0.490	0.452	0.237
Wald statistics	18.74	9.992	15.674	16.417	11.311	22.480
Wald p-value	0.1750	0.7628	0.3337	0.0216	0.1256	0.0693

Notes: R&D intensity is measured as the external R&D expenditure over sales. Investments intensity is measured as additions to machinery, equipment and buildings over total assets. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level. CS estimators using never-treated firms as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

Table A3. CS estimators on the effect of EU ETS on firm's economic performance: control variables measured at *t-2*

	log(Labor productivity) (1)	R&D intensity (2)	Share of STEM workers (3)	Process innovation (4)	Product innovation (5)	Investment intensity (6)
Panel A: Overall aggregation						
Overall EU ETS	0.016	-0.065	-0.049***	0.029	0.213**	-0.013
	(0.1529)	(0.0482)	(0.0126)	(0.0954)	(0.0944)	(0.0506)
Panel B: Group aggregation						
C1: 2005	-0.022	-0.081	-0.054***	0.018	0.189*	-0.010
	(0.1716)	(0.0531)	(0.0144)	(0.1029)	(0.0992)	(0.0579)
C2: 2008	0.399	-0.132	0.001	0.019	0.581**	-0.023
	(0.3756)	(0.1379)	(0.0069)	(0.3215)	(0.2553)	(0.0519)
C3: 2013	0.151	0.282	-0.041	0.371	0.398**	-0.051
	(0.2012)	(0.2015)	(0.0364)	(0.2529)	(0.1674)	(0.0556)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
N. of observations	7,471	7,925	7,765	2,760	2,760	7,808
Outcome mean	154,935	0.222	0.013	0.510	0.490	0.091
Wald statistics	18.012	11.223	18.951	19.194	9.525	11.531
Wald p-value	0.2062	0.6685	0.1668	0.0076	0.2171	0.6439

Notes: R&D intensity is measured as the external R&D expenditure over sales. Investments intensity is measured as additions to machinery, equipment and buildings over total assets. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in *t-2*, and aggregated industry-level. CS estimators using never-treated as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

Table A4. CS estimators on the effect of EU ETS on firm's economic performance: alternative innovation measures

	log(Labor productivity) (1)	TFP (2)	Log(Number of STEM workers) (3)	Share of patent revenues (4)	Internal R&D intensity (5)
Panel A: Overall aggregation					
Overall EU ETS	0.162	-0.021	-0.194	-0.004	-0.036
	(0.1907)	(0.0404)	(0.2053)	(0.0087)	(0.2915)
Panel B: Group aggregation					
C1: 2005	0.159	-0.027	-0.210	-0.007	-0.106
	(0.2033)	(0.0447)	(0.2320)	(0.0095)	(0.3030)
C2: 2008	0.305	0.076	-0.167*	-0.001	1.090
	(0.4293)	(0.0685)	(0.0986)	(0.0058)	(1.108)
C3: 2013	-0.004	-0.040	0.077	0.054	0.620
	(0.1344)	(0.0451)	(0.1923)	(0.0473)	(0.6471)
Other controls	Yes	Yes	Yes	Yes	Yes
N. of observations	6,050	6,045	6,194	6,097	2,332
Outcome mean	713,476	-0.339	3.262	0.012	1.286
Wald statistics	10.271	37.469	10.636	16.011	13.067
Wald p-value	0.7421	0.0006	0.7144	0.3127	0.5212

Notes: Share of patent revenues is measured as the total revenues from patents and licenses over total sales. R&D intensity is measured as the internal R&D expenditure over sales. Control variables include firm size (number of employees), OP TFP, energy costs, share of STEM workers and R&D expenditure measured in 2000, and aggregated industry-level. CS estimators using never-treated firms as the control group. *** ($p < 0.010$), ** ($p < 0.050$), and * ($p < 0.100$), respectively.

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