



CENTRE FOR
STRATEGIC AND
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WORKING PAPER

LEARNING FROM MARKETS: EVIDENCE OF THE EFFECTIVENESS OF THE EMISSIONS TRADING SYSTEMS (ETS)





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Working Paper by CSIS Indonesia

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Abstract

This paper provides new empirical evidence of the effectiveness of Emissions Trading Systems (ETS) in reducing greenhouse gas emissions. Using a panel dataset spanning 1995-2023 across countries, we employ difference-in-differences framework specifically designed for staggered treatment adoption, addressing recent critiques of traditional two-way fixed effects models that can produce biased estimates when treatment effects are heterogeneous. We find that ETS implementation leads to substantial reductions in greenhouse gas emissions, with estimates suggesting a 19 percent decline in GHG emissions on average across all post-implementation periods. These effects are particularly pronounced in the power generation sector (30.2 percent reduction) and industrial combustion (27.9 percent reduction), while transportation shows more modest but still significant decreases (8.4 percent). The impact of ETS strengthens over time, with emissions declining by approximately 23.1 percent after ten years of implementation. We find heterogeneous effects across implementation cohorts. Our results remain robust when controlling for concurrent carbon taxation policies and when examining carbon intensity measures, indicating that ETS can effectively induce transitions toward less emissions-intensive production structures.

JEL codes: Q52; Q58; Q54; H23; C23

Keywords: Emissions Trading System, Carbon Markets, Carbon Pricing, Climate Policy, Policy Evaluation

Table of Contents

Abstract	1
Table of Contents	2
Introduction	3
The Recent Trends of Global ETS.....	6
Literature Review	9
Methodology and Data.....	12
4.1. Methodology.....	12
5.2. Data Sources	14
Results.....	17
5.1 Baseline Results.....	17
5.2 Learning from Others	25
5.3 Mechanism: ETS Leads Economies Moving Away from Carbon-intensive Economy	28
Robustness Checks.....	30
6.1. Does Carbon Tax confound the impact of ETS?.....	30
6.2 Does Carbon Leakage explain Emissions Reduction in ETSs' Jurisdictions?.....	31
Conclusions	37
References	39
Appendix	42

Introduction

Climate change represents one of the most pressing economic challenges of our time, with greenhouse gas emissions posing significant global externalities. While various policy instruments exist to address this challenge, market-based mechanisms, particularly Emissions Trading Systems (ETS), have emerged as a popular solution by creating price signals to internalize environmental costs. By establishing a cap on emissions and enabling market-based trading of allowances, ETSs provide firms with financial incentives to reduce emissions efficiently. Over the past two decades, ETSs have been widely adopted, with jurisdictions such as the European Union, China, and California integrating these mechanisms into their broader climate strategies (Ellerman, Convery, & de Perthuis, 2010; Martin et al., 2016).

Despite the growing adoption across jurisdictions, empirical evidence of the effectiveness of these systems remains mixed, with ongoing debates about their ability to deliver truly emissions reductions. Empirical evaluations of ETSs in developed economies suggest that they can lead to significant emissions reductions (Ellerman et al., 2016; Borghesi & Montini, 2022). The EU ETS, as the world's largest and most established carbon market, has demonstrated a capacity to curb emissions while maintaining economic growth, largely through its cap reductions, dynamic allocation mechanisms, and price stabilization features (Hintermann, Peterson, & Rickels, 2016).

However some are sceptical that the market based solution could deliver its promise in reducing emissions. Ellerman and Buchner (2008) document how the first phase of the EU ETS suffered from excessive allowance allocation, leading to price collapses and minimal abatement. Similarly, Koch et al. (2014) show how the EU ETS failed to adapt to economic downturns, resulting in persistently low carbon prices. Beyond Europe, studies of China's pilot programs reveal issues with price volatility and market liquidity (Liu and Zhang, 2023). Moreover, concerns about carbon leakage—where emissions-intensive activities relocate to unregulated jurisdictions—raise questions about the global effectiveness of regional trading systems (Fowlie et al., 2016).

The empirical literature evaluating ETS effectiveness has provided mixed evidence, with most studies limited to single-country or regional analyses. Bai and Ru (2024) offers cross-country evidence suggesting significant emissions reductions following ETS implementation. Their study employs a conventional staggered difference-in-differences approach with two-way fixed effects (country and year fixed effects) to exploit cross-country and time variation in ETS adoption. While effective for estimating average policy impacts, the two-way fixed effects (TWFE) framework can yield biased estimates when treatment effects vary across groups or over time (Callaway and Sant'Anna 2020). Bai and Ru's design does not fully address these pitfalls of heterogeneous policy timing.

This paper provides new empirical evidence of the effectiveness of ETS in reducing greenhouse gas emissions. Using a panel dataset spanning 1995-2023 across 216 countries, we employ the Callaway and Sant'Anna (2020) difference-in-differences framework specifically designed for staggered treatment adoption (henceforth CS 2020). This methodological approach also addresses recent critiques of traditional two-way fixed effects models that can produce biased estimates when treatment effects are heterogeneous over time or across groups (Goodman-Bacon, 2021; de Chaisemartin and D'Haultfœuille, 2020).

In addition, our paper contributes to the literature in several ways. Using CS 2020, we are able to estimate the temporal dynamics of emissions reductions following ETS implementation. This suggests that the magnitude of abatement often evolves over time rather than fully formed in the first few years. This shows that policy effects may need take some time – companies may require a few years to adjust capital and technological mixes in response to carbon pricing, or early phases of trading (often with generous allowance allocation) yield limited abatement with larger impacts emerging in later phases. We also show that emissions reductions under ETS are concentrated in particular sectors. This heterogeneity in impacts underscores that the effectiveness of ETS can vary within an economy, and it highlights the importance of sectoral policy regulations.

Our paper also reveals the importance of policy learnings. That is, we find evidence of *cohort learning* – later adopters of ETS appear to achieve greater and faster emissions reductions than earlier adopters. We compare treatment effects across different implementation cohorts (e.g. countries that launched ETS in the mid-2000s vs. those in the 2010s). We find that the second generation of carbon markets (programs started after 2010) have, on average, more pronounced emissions impacts than the pioneering systems like the EU ETS in its initial phase. It may suggest that policy design has improved over time: jurisdictions implementing ETS more recently have benefited from the lessons of the early markets (“learning from markets”), adopting best practices in cap-setting, allocation, and compliance enforcement.

Our analysis yields several important findings. First, we find that ETS implementation leads to substantial reductions in greenhouse gas emissions, with estimates suggesting a 19 percent decline on average across all post-implementation periods. These effects are particularly pronounced in the power generation sector (30.2 percent reduction) and industrial combustion (27.9 percent reduction), while transportation shows more modest but still significant decreases (8.4 percent). Notably, the impact of ETS strengthens over time, with GHG emissions declining by approximately 23.1 percent after ten years of implementation. We find heterogeneous effects across implementation cohorts, with

later adopters achieving significant reductions that suggest important learning effects in ETS design and implementation.

The remainder of the paper is organized as follows. Section 2 discusses recent trends in global emissions trading systems. The related literature will be highlighted in section 3. Section 4 describes our methodology and data, detailing the Callaway and Sant'Anna (2020) framework and our comprehensive panel dataset. Section 5 presents our main results. We conduct several robustness checks provided in section 6. Finally, Section 7 concludes with policy implications and directions for future research.

The Recent Trends of Global ETS

The key discussion surrounding the market approach to address climate change is on how we price carbon. There are three types of main carbon pricing instruments (CPIs) implemented globally: emissions trading system (ETS), crediting mechanism, and carbon tax.¹ An emissions trading system (ETS) limits total emission in one or more economic sectors. The government typically issues several tradable allowances that do not exceed the cap level. In practice, each allowance is typically equivalent to one ton of emissions. After that, ETS-covered entities are permitted to trade these allowances, resulting in a market price for the allowances. This is also known as a "cap and trade system." On the other hand, carbon taxes impose a fixed price per unit of emission to internalize the cost of emissions and provide incentives for emission reductions. Lastly, offsetting, or crediting mechanisms are carbon credits given due to emission reductions by an entity. In the market, crediting mechanisms take various forms, but they all work by establishing a baseline level or intensity of emissions.

In the past few years, we have seen an upward trend in carbon pricing instruments (see Figure 1). Despite the geopolitical tensions that were causing energy crisis issues, carbon pricing instruments (CPIs) remained strong and were strengthening. Carbon pricing instruments, under the platform of Emission Trading Systems (ETS) or carbon tax, reached 70 instruments globally until 2022, an increase of 11.1% from 2021. In terms of Green House Gas (GHG) emissions, the 2022 CPIs covered at least 23% of total GHG emissions globally. In terms of coverage, the most recent CPI figure still falls short of the commitment to keep global warming to 1.5 degrees Celsius above pre-industrial levels.

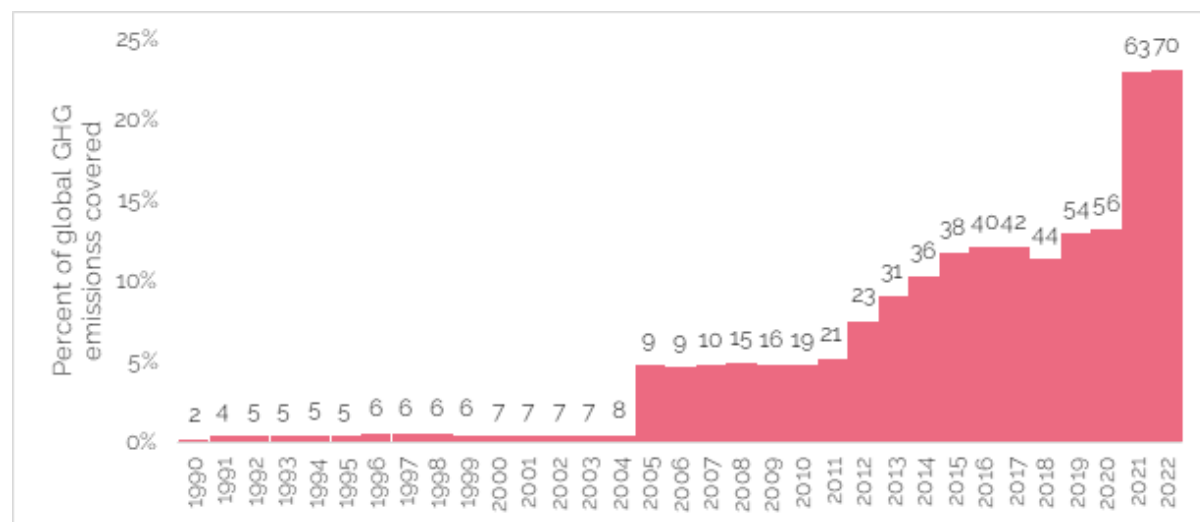
Data from the World Bank (2022) also suggested that more countries and jurisdictions within a country had implemented CPIs in various forms. For example, Uruguay just implemented a carbon tax in January 2022. Indonesia was scheduled to have CPI implemented last year, together with Austria. Meanwhile, other countries such as Israel, Malaysia, and Vietnam announced their intention to develop an Emission Trading System (ETS).

Recent data also suggest that carbon taxation is a marginally popular CPI, but ETS is catching up (see Table 1). As of 2022, 36 CPIs were in the form of carbon taxes, which is slightly higher than that of ETs, which were 34 instruments. Some jurisdictions, at the national and regional level, implement both carbon taxes and ETs. Many European

¹ Carbon tax is not fully market-based as the pricing mechanism is regulated by the government. However, to make the carbon-tax equivalent to the market price, the tax rate is typically adjusted with the market price.

countries have implemented both carbon taxes and ETS, the former being more popular. On the other hand, ETSs have been more popular in East Asia and North America.

Figure 1. ETS emission platforms and GHG Emission Coverage



Note: Label represent the number of CPIs. Two carbon pricing instruments

Source: The World Bank, State and Trends of Carbon Pricing 2022

Table 1. ETS & Carbon Tax by Region

Region	Carbon Tax	ETS	Total
East Asia & Pacific	2	13	15
Europe and Central Asia	19	7	26
Latin America and the Caribbean	8	1	9
North America	6	13	19
Sub-Saharan Africa	1		1
Total	36	34	70

Source: The database from State and Trends of Carbon Pricing, the World Bank 2022. Authors' calculation.

At the global level, the world's largest carbon market in terms of emissions is China, with a reported compliance rate of 99.5% by 2021. In 2021, 179 million tCO₂ equivalent of allowances were traded, representing a total turnover of nearly 7.7 billion yuan (USD 1.2 billion). While this represents relatively low volumes for a market the size of the Chinese ETS, it is not insignificant given that the Chinese ETS is still in the early stages of

implementation—compliance trading only began in earnest in October 2021, and only covered entities (i.e., not financial institutions) that are currently permitted to trade.

In addition, around 15 billion EU emission allowances were exchanged on the Intercontinental Exchange, the largest secondary market platform, with spot prices almost doubling throughout the year. In July 2021, the EU Climate Law took effect, setting a binding EU-wide climate target to reduce GHG emissions by 55% in 2030 compared to the 1990 levels and to reach net zero emissions by 2050. The "Fit for 55" plan comprises a new ETS for transportation and buildings.

In 2022, the value of ETS carbon pricing was almost ninefold that of carbon tax. ETS markets in 2022 were valued globally at around USD 248 billion, and the carbon value under the carbon tax system was USD 29.1 billion. Europe and Central Asia accounted for around 64% of the total carbon market value from the ETS. This is followed by East Asia and the Pacific, dominated by more established markets such as China, New Zealand, Korea, and Japan. Surprisingly, the carbon value under the ETS in North America was relatively lower, around USD 23.4 billion, or around 9% of the total carbon value under the ETS market.

Regarding revenue, the government's revenues under the ETS were more than double those collected from the carbon tax system in 2021. As of 2021, the revenue collected from ETSs globally was around USD 56.4 billion, which is two times higher than the revenue collected from the carbon tax system (around USD 28 billion). The governments in Europe and Central Asia, in total, received around USD 47.9 billion from ETS markets, which accounted for around 85% of total government revenue globally. This was followed by North America, where the revenue collected from ETS was around USD 6.5 billion, or around 11% of total global government revenue. Different from other regions, moreover, the governments in North America received more from the carbon tax than from the ETS market. The carbon tax generated approximately USD 7.3 billion in government revenue in North America in 2021.

Literature Review

Recent studies on the effectiveness of market-based instruments, particularly emissions trading systems (ETS), has highlighted both framework and practical issues that arise during implementation. Tietenberg (2006) provides a perspective on the principles and practice of emissions trading, illustrating how cap-and-trade mechanisms, when supported by robust monitoring and compliance, can achieve significant emissions reductions at lower cost than top-down regulations. In his analysis, Tietenberg underscores the importance of setting a stringent cap, properly allocating allowances, and ensuring transparent price signals so that firms can effectively trade emissions permits. Overly generous caps, on the other hand, risk undermining the environmental effectiveness of such schemes.

In the practical context, empirical research on the European Union Emissions Trading Scheme (EU ETS) has often served as a benchmark for understanding the outcomes of ETSs. Ellerman, Convery, and de Perthuis (2010) document the early experiences of the EU ETS, demonstrating how the system's initial phase (2005–2007) suffered from allowance over-allocation, which curbed emissions price signals and, by extension, the scheme's impact on actual abatements. Despite this shortcoming, they show that the EU ETS established critical institutional and market structures that facilitated more stringent emissions reductions in subsequent phases. At firm-level data, Martin et al. (2016) assess how free allowance allocations affect the risk of relocation among regulated enterprises. Contrary to concerns that the ETS would erode European competitiveness, their findings indicate that relocation pressures were modest, suggesting that compensatory measures and flexible trading options helped mitigate carbon leakage.

Some studies focus on the impact of ETS-like policy in major developed countries. Fowlie, Holland, and Mansur (2012) evaluate Southern California's RECLAIM program, demonstrating that allowance trading does deliver cost savings compared to prescriptive command-and-control approaches, although they highlight potential inequities in emission "hot spots" if trades concentrate pollution in certain localities. Murray, Maniloff, and Murray (2014), in a study on the Regional Greenhouse Gas Initiative (RGGI), attribute emissions declines in participating states to both the policy constraints of RGGI and exogenous factors such as the economic downturn and historically low natural gas prices. Their findings reinforce the idea that an ETS may operate in tandem with larger market trends and cannot be viewed in isolation.

Although studies supporting evidence that ETS can reduce greenhouse gas emissions cost effectively, there are also critical research that question whether these market-based mechanisms fulfil their environmental promises. Some critics have called the structural integrity and the real-world implementation of these markets. Wara (2007), for example, points out that overly generous allocation of permits can undermine the environmental

effectiveness of an ETS by suppressing allowance prices and attenuating firms' incentives to invest in cleaner technologies. The first phase of the European Union Emissions Trading Scheme (EU ETS) offers a salient illustration; while Ellerman, Convery, and de Perthuis (2010) view it as an indispensable pilot phase that helped build institutional capacity, Wara (2007) describes that the misalignment between actual emissions and the cap eroded confidence in market signals. Other empirical work, such as that by Hintermann (2010), provides evidence of how price volatility and thin trading volumes in early ETS phases further complicated firms' strategic planning, raising questions about the reliability of allowance markets to deliver stable price incentives over time.

Other critics emphasize the potential for allowances and offset loopholes to dilute true emissions reductions. Based on case studies in the Clean Development Mechanism (CDM), Wara and Victor (2008) contend that carbon-offset projects often overstate their environmental benefits, effectively enabling net global emissions to remain unchanged while regulated entities comply on paper. Their analysis stresses that if regulations around offsets are not stringent and carefully monitored, ETS can facilitate a mere reshuffling of emissions rather than fostering genuine emissions declines. Victor (2011) echoes these concerns in his broader discussion of global climate policy deadlock, arguing that the complexity of international carbon markets creates ample room for gaming the system and stalling more direct policy action.

Petrack and Wagner (2014) use difference-in-differences method to evaluate the impact of ETS on German firms. They find that while the EU ETS had only modest negative impacts on competitiveness, the actual abatement achieved in certain energy-intensive subsectors was limited. Similarly, Borghesi, Cainelli, and Mazzanti (2015) identify a positive link between EU ETS participation and firm-level environmental innovation in Italy, but they mention that when caps are not sufficiently stringent, the incentive to adopt transformative low-carbon technologies diminishes over time. Meanwhile, Dechezleprêtre and Sato (2017) survey a range of econometric analyses on the competitiveness impacts of climate regulations, including ETS, underscoring that policy design remains paramount: if free allowances and offset provisions are too generous, reductions in emissions are often marginal relative to the stated goals.

Our paper is closely related to Bai and Ru (2024), who provide evidence on ETS effectiveness. Using a panel of the 100 largest countries by GDP and a staggered difference-in-differences approach, they found that ETS adoption materially reduced greenhouse gas emissions by 12.1% and carbon dioxide emissions by 18.1%. Moreover, they identified mechanisms underlying these reductions, demonstrating that ETS implementations reduced fossil fuel usage, particularly coal (by 23.7%), while boosting renewable energy usage (by 61.6%). Their comparison of carbon trading versus carbon

taxes suggests that ETS is more effective in driving both emissions reductions and renewable energy adoption.

While Bai and Ru's work represents an important advancement in understanding global ETS impacts, our study undertakes several methodological improvements upon theirs. Our analysis employs the Callaway and Sant'Anna (2020) framework specifically designed for staggered treatment adoption, which addresses recent critiques of traditional two-way fixed effects models that can produce biased estimates when treatment effects are heterogeneous.

By employing the Callaway and Sant'Anna (2020) framework with staggered adoption timing, our study provides a more robust and credible identification of causal effects than them. Our approach explicitly addresses recent methodological critiques of two-way fixed effects models (Goodman-Bacon, 2021; de Chaisemartin and D'Haultfœuille, 2020), delivering robust estimates of dynamic treatment effects.

To summarize, while a significant portion of the literature (e.g., Tietenberg 2006; Martin et al. 2016; Fowlie, Holland, & Mansur 2012) supports the premise that well-designed emissions trading systems can reduce emissions in a cost-effective manner, others (Wara 2007; Wara & Victor 2008; Victor 2011) have raised legitimate concerns about over-allocation, offset loopholes, transaction costs, and price volatility. Empirical evaluations that employ econometric methods (e.g., Petrick & Wagner 2014; Borghesi et al. 2015; Dechezleprêtre & Sato 2017) suggest that these downsides are not simply theoretical. Instead, they underscore that the success or failure of an ETS rests largely on the details of policy design and implementation—factors that can either reinforce the environmental integrity of trading programs or undermine their long-term capacity to drive a transition to low-carbon production.

Methodology and Data

4.1. Methodology

Countries that implemented ETS have certain characteristics that failure to control the characteristics would bias the parameters of interest. For example, countries with more ambitious commitments for reducing emissions would be more likely to establish various instruments for pricing carbon, including ETS. Thus if we do not control for this factor, the impact of ETS on emissions might be biased upward. Moreover, ETS has been implemented in various timing. Some countries experimented with ETS at the subnational level before they scaled up to the national level. Hence a difference-in-differences model is not able to tease out the impact of ETS.

We employ the methodological framework developed by Callaway and Sant'Anna (2020) to identify and estimate the effects of Emission Trading Scheme (ETS) implementation on greenhouse gas (GHG) and CO₂ emissions. This methodology is particularly suited to our context, as ETS policies are implemented at different points in time across countries.

The standard staggered difference-in-differences (DiD) estimation using Two-Way Fixed Effects (TWFE) regression models implicitly assumes homogeneous treatment effects across units and over time. Recent literature, however, highlights significant limitations in these conventional TWFE methods, especially when treatment effects vary over time or across groups (Goodman-Bacon, 2021; de Chaisemartin and D'Haultfœuille, 2020). Specifically, standard TWFE regressions may produce biased estimates due to negative weighting of heterogeneous treatment effects (Borusyak and Jaravel, 2017; Sun and Abraham, 2021).

In this paper we adopt the DID framework of Callaway and Sant'Anna (2020) with staggered treatment timing (multiple periods and groups). The framework is first to identify group-time average treatment effects $ATT(g, t)$ —the effect for units treated in group g (first treated in period g) at time t —and then aggregate these into interpretable parameters. Specifically, the group-time average treatment effect parameter is as follows

$$ATT(g, t) = E[Y_t(g) - Y_t(0) | G = g]$$

[1]

Where $Y_t(g)$ denotes the potential outcome at time t for units first treated at period g , $Y_t(0)$ denotes the untreated potential outcome; $G = g$ denotes the group first treated at period g .

Identification relies on two key assumptions: (i) limited treatment anticipation and (ii) conditional parallel trends, where parallel trends hold after conditioning on observed covariates. Under these assumptions, $ATT(g, t)$ can be identified by comparing changes in outcomes between the treated group and an appropriate control group (units not treated by time t). In our case, we use never-treated as control group.

In estimating *group-time* ATT we use a doubly robust estimator combining inverse probability weighting (IPW) and outcome regression (OR). Specifically we estimate the following parameter

$$ATT_{dr}^{nev}(g, t; \delta) = \mathbb{E} \left[\left(\frac{G_g}{\mathbb{E}[G_g]} - \frac{\frac{p_g(X)C}{1 - p_g(X)}}{\mathbb{E} \left[\frac{p_g(X)C}{1 - p_g(X)} \right]} \right) (Y_t - Y_{gg-\delta-1} - m_{g,t,\delta}^{nev}(X)) \right] \quad [2]$$

Where G_g denotes membership in group g ; C is the control group; $p_g(X)$ is the propensity score which represents the probability of being treated at time g conditional on covariates X and on either being a member of group g . $m_{g,t,\delta}^{nev}(X) = E[Y_t - Y_{g-1} \mid X, C = 1]$ is the outcome regression for the never-treated group.

Specification 2 provides us with treatment effects from different group and time. We can use this to highlight treatment effect heterogeneity across different group g at different points in time. For our purpose, we may combine these different $ATT(g, t)$'s to provide us with more aggregated causal parameters. In the following we consider different aggregation methods for $ATT(g, t)$'s that allow us to have measures of the causal effects of ETS.

We are also interested in the effect of ETS that depends on the length of the ETS implementation. To investigate the evolution of treatment effects by exposure duration, we aggregate by event time, in which $e = t - g$. Specifically we compute the following

$$\theta_D(e) = \sum_{g: g+e \leq t} ATT(g, g+e) P(G = g \mid G+e \leq t) \quad [3]$$

$\theta_D(e)$ describes the dynamic effects at different time horizons since treatment initiation. This is parameter that is typically used for the event study.

We can compute an aggregated parameter to highlight treatment effect heterogeneity with respect to calendar time. The average effect of participating in the treatment in time period t (across groups that have adopted the treatment by period t) is given by

$$\theta_c(t) = \sum_{g \leq t} ATT(g, t) P(G = g | G \leq t)$$

[4]

$\theta_c(g)$ aggregates effects across all groups treated by calendar period t . This provides insights into temporal variations of treatment effects. In the following, we could estimate the group-specific effects. That is, the average treatment effect for each treatment cohort (group-specific effects) can be calculated as follows

$$\theta_s(g) = \frac{1}{T - g + 1} \sum_{t=g}^T ATT(g, t)$$

[5]

$\theta_s(g)$ captures the average impact for each treatment cohort from the point of treatment onward. The group-specific effects gives us insight to which groups with higher magnitude in reducing emissions.

Finally, we can have the overall aggregated effect. In this, we compute an overall effect summarizing all post-treatment effects across groups and periods. Specifically we compute the following

$$\theta^{overall} = \frac{\sum_{g \in G} \sum_{t=g}^T ATT(g, t) P(G = g | G \leq T)}{\sum_{g \in G} \sum_{t=g}^T P(G = g | G \leq T)}$$

[6]

$\theta^{overall}$ provides a single interpretable summary of the average effect of ETS implementation for all treated units.

Inference is conducted using a multiplier bootstrap procedure, following Callaway and Sant'Anna (2020). This approach allows for construction of simultaneous confidence intervals, accounting robustly for multiple hypothesis tests across groups, time periods, and event times.

5.2. Data Sources

Our empirical analysis draws from panel dataset spanning from 1995 to 2023. The long panel data allow us to have enough pre-ETS implementation period. The data are sourced from the World Bank's World Development Indicators (WDI) and the *State and Trends of Carbon Pricing* reports. Dependent variables include greenhouse gas (GHG) emissions metrics. Total CO₂ emissions—excluding contributions from Land Use, Land-Use Change, and Forestry (LULUCF)—are disaggregated by sector, encompassing

agriculture, energy (with subsectors such as industrial combustion, fugitive emissions, and power generation), industrial processes, and waste. We adjust the emissions into per capita and transform into natural logarithm.

The key to our analysis is the timing of the ETS implementation. The implementation time of ETS is sourced from the World Bank's State and Trends of Carbon Pricing Report (2024) that contains information of the year that the ETS is implemented. We construct the event time by taking the difference between the current year with the year of ETS implementation. A negative value of the event time indicates the number of years before the implementation and a positive value indicates the number of years after the implementation.

Some countries such as US, Canada, and China have ETS implemented at subnational level first and subsequently has been implemented in the national level (e.g. China). In that case, we assign any ETS implemented first at subnational level to national level. For example, Guangdong—a province in China—implemented the ETS in 2013. This is the first the ETS is implemented in China. Meanwhile China implemented the ETS at the national level in 2021. Despite this, we assign the ETS timing in China at 2013, that is, the year that the ETS is implemented at sub-national level.

We also assume that ETS started at sub-national level is implemented at the national level. The US, for example, has not implemented the ETS at the national level. However, the northeastern states of the US adopted the Regional Greenhouse Gas Initiative (RGGI) in 2009 which essentially limits carbon dioxide emissions from electricity generation through a regional emission trading program. In that case, we assign the US as if it would have implemented the ETS by 2009.

The implication of assigning the timing of subnational ETS as the national ETS potentially lead to upward bias to the extent that ETS has no impact on emissions. That is, given that ETS is implemented at subnational level while we measure emissions at the national level, the impact of the subnational ETS may be marginal in reducing the country-level emissions. Thus, in the robustness check, we exclude countries implementing subnational ETS and assess the extent to which parameters of interest change.

Control variables include the real GDP per capita in constant US dollar, converted to natural log. We also include the share of value added to GDP in agriculture and industry sectors. To tease out the effect of international trade on emissions, we include the share of trade—i.e. exports and imports—in GDP. Country-level fixed effects and region-year fixed effects are included to address unobserved heterogeneity and regional trends, respectively.

Table 4.1 exhibits descriptive statistics of our outcomes and also covariates. First of all, in terms of emissions, we observe that countries implementing ETS tend to have higher

emissions. Compared to countries with ETS, the GHG emissions of countries implementing ETS is more than fivefold to that of countries without ETS. Emissions stemming from other sectors are also found higher in the ETS countries than non-ETS countries.

On other covariates, we find that on average, the ETS countries have higher GDP per capita than non-ETS countries. They also rely more on non-agricultural economic activities. That is, the share of agricultural output to total GDP is only 4.57%, which is lower than that of countries without the ETS. The ETS implementing countries are also more open to external markets through trade, indicated by relatively higher share of trade (both exports and imports combined) to GDP.

Table 4.1 Descriptive Statistics of Variables

Variables	No ETS	ETS	Difference	P-val
Emission (Mt CO₂e)				
GHG	101.20 (348.44)	595.11 (1738.35)	-493.91	0
CO ₂	65.22 (250.19)	455.32 (1414.53)	-390.10	0
CO ₂ Industrial Combustion	9.99 (44.15)	82.21 (330.91)	-72.22	0
CO ₂ Industry Processing	4.74 (17.34)	36.66 (153.24)	-31.91	0
CO ₂ Power	26.91 (117.76)	172.55 (599.19)	-145.63	0
CO ₂ Transportation	11.27 (32.96)	85.50 (239.65)	-74.23	0
Covariates				
Natural Log of GDP per capita	8.08 (1.30)	9.69 (1.04)	-1.61	0
Percent of Agriculture Value Added (% of GDP)	14.47 (11.08)	4.57 (4.83)	9.90	0
Percent of Manufacturing Value Added (% of GDP)	27.05 (13.37)	26.30 (8.25)	0.75	0.0488
Percent of Trade (% of GDP)	82.46 (46.83)	97.30 (63.90)	-14.85	0
Observation	3229	1404		

Note: Authors' calculations from dataset

Results

5.1 Baseline Results

We begin our analysis by presenting the results of the event study model—i.e. the specification 1. Other covariates we use include natural logarithm of real GDP per capita, the natural logarithm of real GDP per capita square, value added of agriculture and industry—as percentage of GDP, international trade—i.e. value of exports and imports—as percentage of GDP. To estimate the treatment effects by exposure duration, we use a doubly robust estimator combining inverse probability weighting (IPW) and outcome regression (OR). Specifically, we estimate $\theta_D(e)$ in which e is the length of the exposure after the implementation of ETS. We then plot $\theta_D(e)$ with 95 percent of confidence interval. The results from the plotted $\theta_D(e)$ s are presented in the following charts. In short, the event study captures the dynamic treatment effect of ETS implementation on greenhouse gas (GHG) emissions, allowing for an examination of the temporal impact of market-based carbon pricing mechanisms.

We begin with the greenhouse gas emission (GHG) (tonne CO2 equivalent), excluding LULUCF. This GHG emissions cover emissions coming from total annual emissions of the six greenhouse gases (GHG) covered by the Kyoto protocol, standardized to carbon dioxide equivalent values.² The chart describes the change of GHG emissions before and after the implementation of Emissions Trading Systems (ETS) globally using an event study model.

Figure 2 shows that the ETS implementation leads to a gradual and significant reduction in GHG emissions over time. Prior to implementation, emissions appear relatively stable, with no discernible downward trend. This suggests that the parallel trend assumption hold. That is, there is no evidence that emissions trajectories between countries implementing ETS and non-implementing countries are statistically different. It means that the GHG emissions trajectories in the absence of ETS would have likely continued at similar levels, affirming the credibility of the counterfactual.

Following ETS adoption, however, emissions exhibit a significant downward trend, with the magnitude of the decline increasing as additional years elapse. We find that by the fifteenth year after the implementation of the ETS, GHG emissions are reduced by 50.4 percent (0.504 times 100 percent) relative to a year before the implementation (Please see Table A.1 in the appendix). The GHG emission reduction is statistically significant at the confidence level of 99 percent.

² Kyoto Protocol covers the following emissions: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphurhexafluoride (SF₆), from the energy, industry, waste, and agriculture sectors.

Figure 2. GHG Emissions Change Before and After ETS Implementation

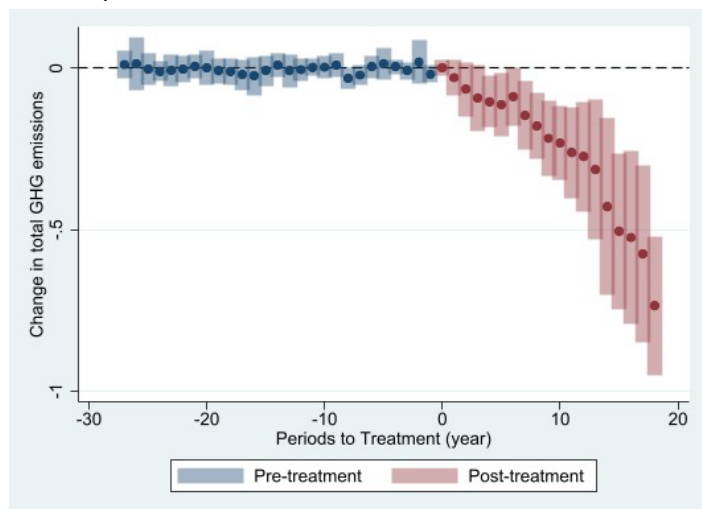
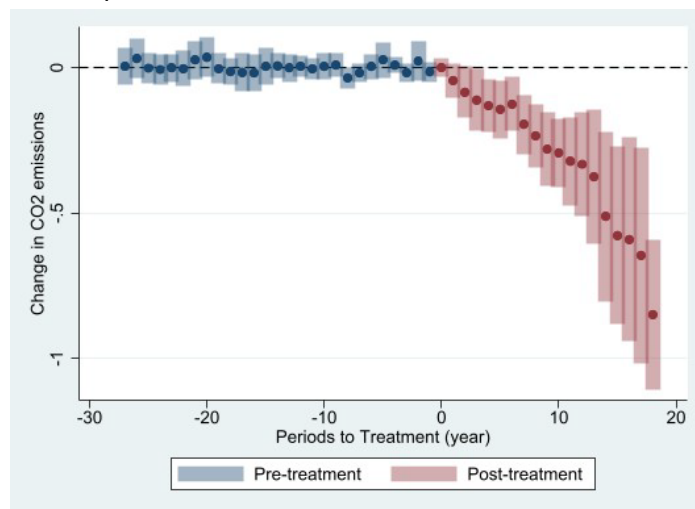


Figure 3. CO2 Emissions Change Before and After ETS Implementation



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented. Other covariates include natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It includes country and year fixed effects. The estimations are within 95% confidence intervals where standard errors are clustered at region level.

Source: Authors' calculation

The declining trend of emissions after the implementation of the ETS is also found in the case of the CO2 emissions. Figure 3 shows that following the implementation of ETS, CO2 emissions reduce significantly. Using the timeframe of fifteen years before and after implementation, our estimate suggests that fifteen years after the program, the emissions is down by more than half—i.e. 57.7 percent and statistically significant at the confidence level of 99 percent. This pattern is consistent in both GHG or CO2 equivalent emission measures. Thus suggest the effectiveness of ETS in mitigating emissions for long period.

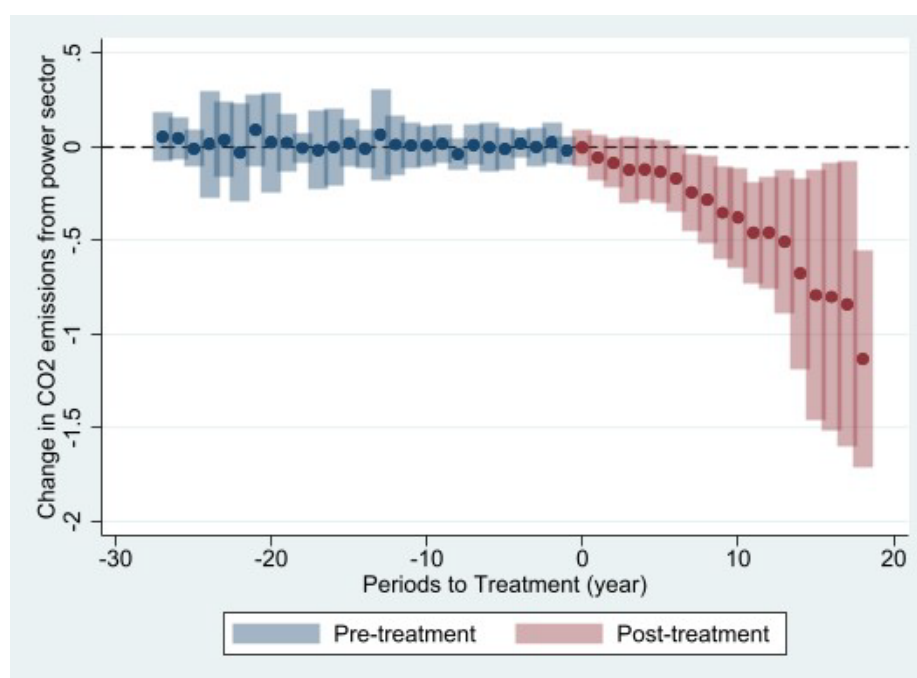
We explore further emissions by sector that are typically regulated by the ETS systems across the majority of jurisdictions. We find that sectoral emissions dynamics reveals heterogeneity in the impact of ETS across different economic activities. However, the reduction of emissions occur almost on all sectors.

The role of the ETS in reducing emissions in power sector is very significant (Figure 4). Without the ETS, the emissions stemming from power generation activities would remain in the same trajectories. Yet the ETS implementation has led to a significant reduction in the emissions from the power sector. In the pre-implementation period, the estimated treatment effects are near zero with no discernible trend, supporting the validity of the

parallel trends assumption critical to our identification strategy. The absence of significant pre-treatment effects suggests that countries implementing ETS did not experience systematically different emissions trajectories in the power sector prior to policy adoption.

Following ETS implementation, we observe an immediate and progressively strengthening reduction in power sector emissions. The magnitude of this effect is substantial, with the coefficient at $t+10$ estimated at -0.378, representing a 37.8% reduction in emissions relative to pre-implementation levels. This effect is statistically significant at the one percent level and continues to intensify in subsequent years, reaching 79.1 percent after fifteen years of implementation.

Figure 4. Change in CO2 Emissions Change Before and After ETS Implementation: Power Sector



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented. Other covariates include natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It includes country and year fixed effects. It also includes the 95% confidence intervals where standard errors are clustered at region level.

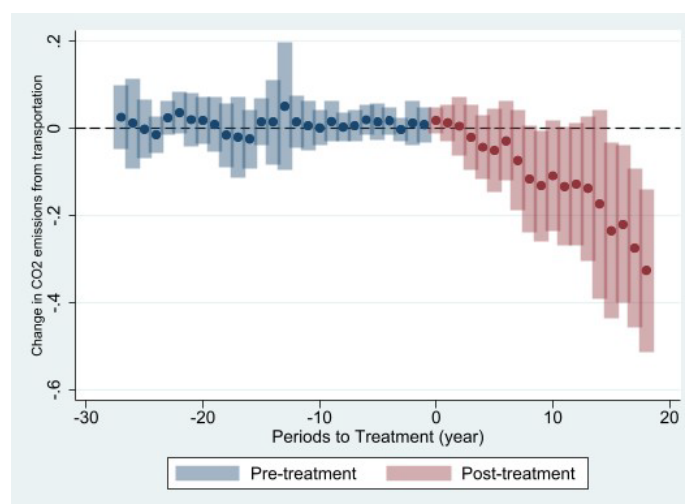
Source: Authors' calculation

The large decline in emissions from power sector likely reflects several factors specific to electricity generation. First, power producers typically face fewer technological constraints in switching to lower-carbon generation sources compared to other sectors. Second, the power sector is generally fully covered under most ETS designs, with minimal exemptions. Third, the relatively concentrated market structure of electricity generation may facilitate more coordinated and rapid responses to carbon pricing signals.

Transportation is another sector impacted by the ETS. Figure 5 highlights that without the ETS, emissions from transportation sector will be on the same trajectories. By fifteen years after the implementation, the ETS reduced the emissions stemming from transportation by 23.4 percent compared to the year before the implementation.

In the pre-implementation treatment effect generally hover around zero, with some periods showing slight positive values. However, these pre-treatment effects are quantitatively small and do not display a consistent trend, largely supporting the parallel trends assumption underpinning our identification strategy. The post-implementation trajectory shows a gradual decline in transportation emissions that becomes statistically significant after several years. Ten years after the program, the estimated effect suggest emissions reduction of 10.8 percent and it is statistically significant at at the 1% level. The decline trajectory of emissions continues in the subsequent years.

Figure 5. Change in CO2 Emissions Before and After ETS Implementation: Transportation



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are clustered at region level.

Source: Authors' calculation

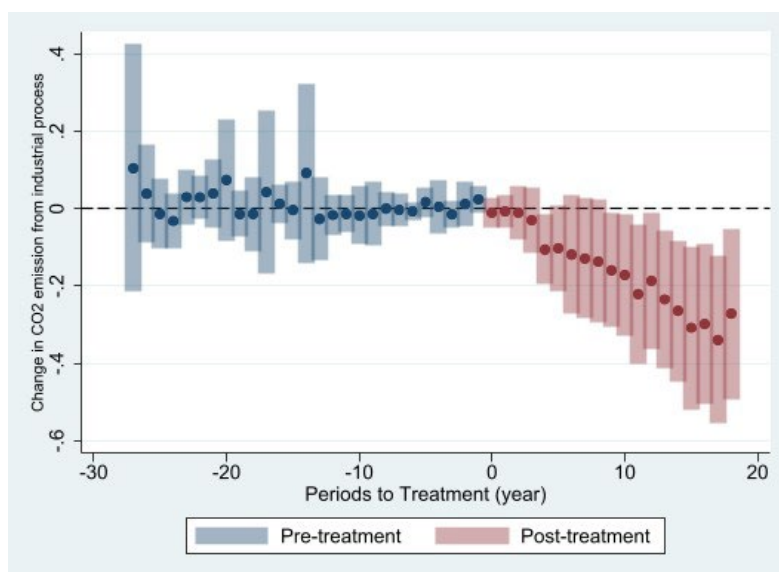
Industrial process and industrial combustion sectors shows downward trends in emissions and are accelerating after the implementation of ETS (see figure 6 and 7). We estimate that fifteen years after the implementation, CO₂ emissions from industrial combustion declined by 53.4 percent, relative to one year before the implementation. Meanwhile emissions from industrial process reduced by 30.7 percent after the ETS implementation. Both highlight significant reductions.

Figure 6 depicts the event study coefficients for CO₂ emissions from industrial processes before and after the implementation of Emissions Trading Systems. The analysis reveals a significant but moderate decline in industrial process emissions following ETS adoption, with distinct dynamics compared to other sectors.

In the pre-implementation period (T-15 to T-1), the estimated coefficients display minimal variation around zero, with no systematic pre-treatment trend evident. Most coefficients are statistically indistinguishable from zero, with the exception of T-1 where we observe a small positive coefficient of 0.024 (standard error = 0.012), significant at the 5% level. This isolated deviation does not undermine the overall validity of the parallel trends assumption critical to our identification strategy.

Following ETS implementation, industrial process emissions show a delayed response, with statistically significant reductions emerging several years after policy adoption. By ten years, the emissions from industrial process reduced by 17.1 percent. The industrial process sector demonstrates a more moderate response to ETS implementation compared to power generation and industrial combustion, but stronger than transportation. This intermediate effect likely reflects complex production methods with limited short-term abatement options and significant capital intensity. Additionally, concerns about carbon leakage and international competitiveness have led many ETS designs to provide partial exemptions or free allowance allocations to emissions-intensive trade-exposed industries, potentially dampening price signals.

Figure 6. Change in CO₂ Emissions Before and After ETS Implementation: Industrial Process

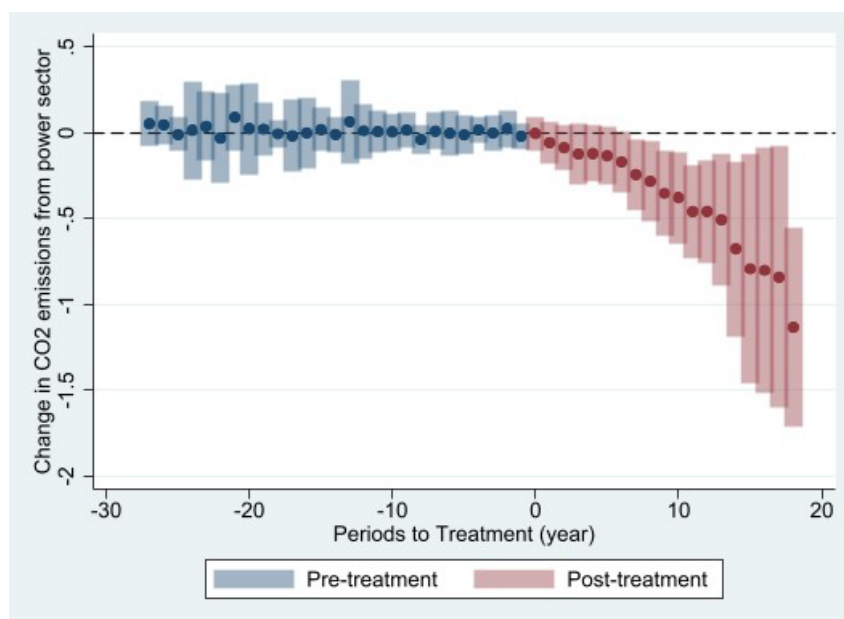


Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are clustered at region level.

Source: Authors' calculation

Figure 7 displays the estimated dynamic impact of Emissions Trading Systems (ETS) on industrial combustion emissions, expressed as the percentage change relative to the year immediately preceding ETS adoption. The chart demonstrates a modest but steady downward shift in CO₂ emissions during the early post-adoption years. Beyond this initial phase, a marked acceleration emerges. Ten years after the program, industrial combustion emissions are roughly 37.3% lower than they would have been absent an ETS (see Table A.1). This also points out that an ETS can provide a potent price incentive for firms to invest in lower-carbon combustion technologies over the medium term.

Figure 7. Change in CO2 Emissions Before and After ETS Implementation: Industrial Combustion



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are clustered at region level.

Source: Authors' calculation

We also calculate the overall impacts of ETS and the results are summarized in Table 2. We calculate the pre-post effects (specification 6), the aggregated group effect (specification) and the aggregated calendar effect. The pre-treatment ("Before ETS") capture the average difference in emissions between treated the ETS adopter countries and untreated countries during the pre-implementation period. We find no evidence that emissions in countries that eventually adopted ETS were on systematically different trajectories from their non-adopting counterparts in the years prior to implementation. This reinforce our parallel-trends assumption central to difference-in-differences identification. One exception is transportation-related CO₂, which shows a small positive effect 0.013 and significant at 5 percent. This may suggest that countries implementing ETS had 1.3 percent higher emissions than that of non-implementing countries. Although this may reflect idiosyncratic dynamics in transportation emissions, the relatively small value (around 1.3%) does not invalidate the broader parallel-trends result.

On the other hand, the overall impact of ETS can be described in the “After ETS” rows. That is, we find that the ETS in overall reduced emissions by 19 percent and its impact is statistically significant at confidence level of 99 percent. Among the sector-specific CO₂ outcomes, power-sector emissions decline by roughly 30.2%, while industrial combustion recorded 27.9 percent emission reductions. These results align with the power and industrial combustion sectors’ well-documented responsiveness to carbon price signals: power generators typically switch to lower-emission sources (e.g., natural gas, renewables), whereas heavy industries reconfigure combustion processes or undertake capital upgrades over the medium term. The ETS also reduced emissions stemming from transportation sector by 8.4 percent, which is relatively modest than for electricity and heavy industry—possibly because transportation emissions often hinge on infrastructure choices, vehicle turnover rates, and preexisting fuel taxes.

The *calendar average impacts* aggregate all treatment effects across the calendar timeline, whereas the *group average impacts* aggregates the dynamic impacts across different cohorts of ETS adopters. Qualitatively, all estimates produce consistent narrative that GHG emissions drop by roughly 16–20%, and CO₂ emissions register slightly larger reductions, particularly in power and industrial combustion.

Taken together, the estimates in Table 2 confirm that ETS implementation is associated with significant abatement across multiple sectors, with the largest effects appearing in power generation and industrial combustion. Even the transportation sector shows a discernible, if more modest, drop in post-adoption emissions. These results lend supports to the argument of well-structured ETS can induce meaningful shifts away from carbon-intensive activities, especially when sufficiently stringent caps and effective monitoring rules bolster confidence in the carbon price signal (Tietenberg 2006; Ellerman et al. 2010).

Table 2. Summary of the ETS Impacts

Variables		GHG	CO2	CO2 Industrial Combustion	CO2 Industrial Process	CO2 Power	CO2 Transportation
Before ETS		-0.002 (0.004)	0 (0.005)	-0.012* (0.006)	0.002 (0.007)	0.007 (0.008)	0.013** (0.005)
After ETS		-0.190*** (0.035)	-0.235*** (0.037)	-0.279*** (0.094)	-0.137*** (0.041)	-0.302*** (0.037)	-0.084*** (0.027)
Calendar Impacts	Average	-0.199*** (0.034)	-0.242*** (0.038)	-0.266*** (0.079)	-0.136*** (0.039)	-0.306*** (0.045)	-0.088*** (0.027)
	Average	-0.157*** (0.025)	-0.197*** (0.028)	-0.212*** (0.060)	-0.098*** (0.029)	-0.264*** (0.030)	-0.058*** (0.018)

Note: The values are the coefficients on the average treatment effects, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It includes country and year fixed effects. It also includes the 95% confidence intervals where standard errors are clustered at region level.

Source: Authors' calculation

5.2 Learning from Others

Countries may have learned and adopted the ETS features from earlier adopter. The European Union's ETS has acted as a global prototype, shaping the architecture of later trading schemes well beyond Europe. Narassimhan et al. (2018) noted that some jurisdictions learned and modified the features of the ETSS. California and Québec appear to have learned significantly from the EU's experience. Rather than starting with full free allocation, California implemented a hybrid approach that included substantial auctioning from the beginning, with benchmarked allocations for industrial facilities and mandatory consignment requirements for electric utilities (Narassimhan et al. 2018). Switzerland also shows evidence of institutional learning by aligning its allocation rules with the EU ETS in preparation for eventual linkage, moving from grandfathering to benchmarking in its second phase. This demonstrates direct learning from the EU's early challenges with over-allocation and windfall profits.

To understand such effect, we estimate the implementation of ETS by cohort. We find that there are certain periods in which significant numbers of countries implementing ETS. The periods are 2005, 2007, 2013 and 2016. In 2005, the EU ETS was implemented

across European Union countries. In 2007 three countries implemented ETS, namely, Bulgaria, Canada and Romania. In 2023, certain countries in East Asia such as China, Hongkong, Croatia and Kazakhstan implemented ETS. Lastly in 2016, four countries—i.e. Chile, Colombia, Turkiye, and Ukraine—launched the ETS.

The estimated effects by cohorts are plotted in Figure 8. This EU ETS cohort shows the largest overall drop, with an estimated reduction of 28.9 percent for total GHG emissions, below what they would otherwise have been (see Table A.3 in appendix). By sector, power generation exhibits the most pronounced reduction 42 percent, aligning with prior evidence that power producers rapidly respond to a credible carbon price by substituting into lower-carbon fuels or ramping up renewable capacity (Ellerman et al. 2010). Industrial combustion recorded 35.4 percent, suggesting that heavy industry likewise adapted significantly once faced with a binding emissions cap and actively traded allowances. Although the EU ETS underwent multiple phases and reforms, this sizable abatement effect underscores that well-structured trading programs can deliver substantial, long-lasting emissions cuts in energy-intensive sectors (Hintermann, Peterson, & Rickels 2016).

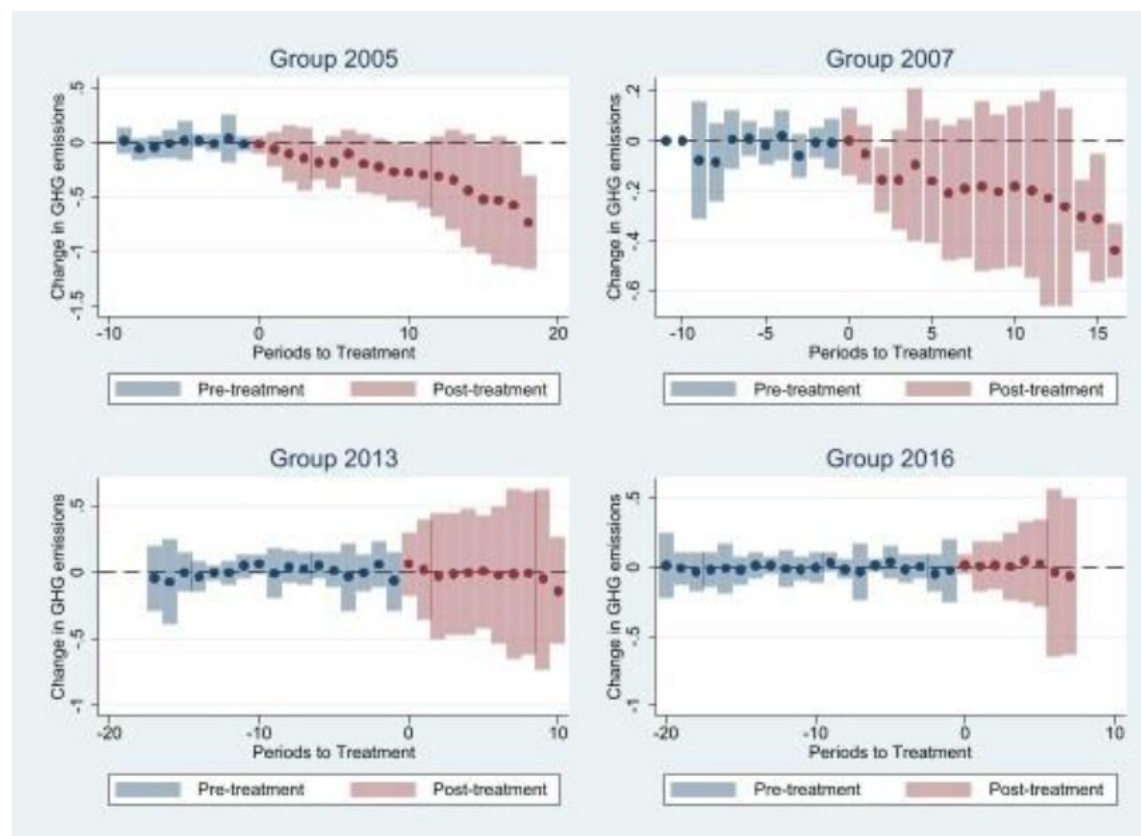
The cohort of 2007 that includes Bulgaria, Canada, and Romania, contributed to a total GHG emissions reduction of 18.6 percent. Meanwhile the cohort of 2013 comprising of some parts of China, Croatia and Kazakhstan, lead to reduced GHG emissions by 1.6 percent and it is not statistically significant at conventional level of 95 percent. The group of 2016 consisting of Chile, Colombia, Turkiye, and Ukraine displays a similar early-stage pattern, with a negative but relatively small coefficient of effect that is -0.035 (around 3.5% lower emissions).

It is clear that the recent cohort suggests a lower or no impact of ETS. This may suggest that early adopters commonly require several years to establish market liquidity, refine allowance allocations, and integrate complementary measures such as carbon taxes or renewable energy mandates. Hence, the limited observed effect may partly reflect the period before covered firms fully commit to emissions-saving capital investments (Dechezleprêtre & Sato 2017).

Overall, the cross-cohort patterns in Figure 8 reinforce two main conclusions. First, the EU ETS stands out in achieving particularly large and persistent reductions—a result that attests to the system’s central role as an early and comprehensive application of cap-and-trade. Second, the more recent adopters, although showing lower initial abatement, demonstrate an emerging downward trajectory consistent with prior experiences: tightening caps, rising carbon prices, and complementary policies often magnify the impact of ETS over time. As coverage expands and regulatory mechanisms mature, many

of these newer systems could ultimately converge toward the more pronounced emissions abatements observed in the pioneering EU program.

Figure 8. Change in GHG Emissions Before and After ETS Implementation by Cohort



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are robust to heteroskedasticity.

Source: Authors' calculation

Our analysis carries important implications for climate policy design and implementation. The varying regional outcomes suggest that successful emissions trading systems require more than just market establishment – they need careful calibration of permit allocation, price stability mechanisms, and sector coverage informed by lessons from earlier implementations. This finding is particularly relevant for countries currently considering or developing their own carbon trading systems.

5.3 Mechanism: ETS Leads Economies Moving Away from Carbon-intensive Economy

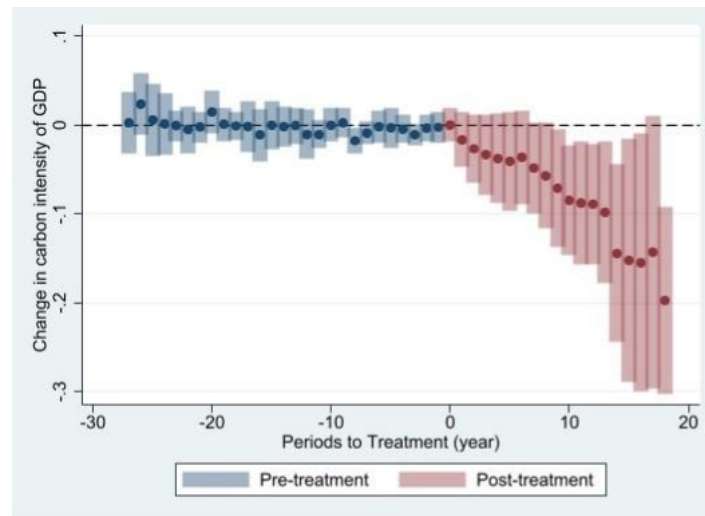
ETS that cap and trade emissions leads companies to adopt technology that emits fewer emissions. Overall, the ETSS potentially drive away from carbon-intensive economy. In this part, we investigate the impact of ETS on carbon intensity—namely, the amount of CO₂-equivalent (CO₂e) emitted per unit of real economic output. Figure 9 illustrates how carbon intensity (measured in kg CO₂e per 2021 PPP USD) evolves before and after ETS implementation, once again controlling for whether a carbon tax is in place. Examining carbon intensity offers a complementary perspective, as it highlights whether cleaner technologies and processes are enabling countries to grow their economies while reducing emissions per dollar of gross domestic product (GDP).

The results suggest that ETS-adopting countries, on average, experience a substantial decline in carbon intensity over the medium and longer horizons following policy enactment. In the initial few years (approximately $T+1$ to $T+3$), carbon intensity levels exhibit only modest differences between ETS implementers and the relevant control group. However, by roughly the fifth year after adoption, the gap widens considerably. By $T+10$, the figure indicates that carbon intensity in ETS jurisdictions is approximately 25–30% lower than the no-ETS counterfactual. Even when accounting for carbon taxes, the observed decrease remains robust, underscoring that a binding cap-and-trade program meaningfully accelerates a shift toward less emissions-intensive production.

Several mechanisms plausibly explain this convergence to a lower carbon footprint per unit of output. First, regulated firms often invest in more efficient capital stock once an ETS is introduced, especially in sectors like power generation and industrial processes where incremental efficiency upgrades can yield substantial cuts in both emissions and variable costs (Ellerman et al. 2010). Second, an ETS aligns corporate financial incentives with pollution prevention, encouraging a shift toward lower-carbon inputs (e.g., renewables in electricity generation or cleaner feedstocks in manufacturing). Third, and just as significant, the presence of a carbon tax often complements the ETS by providing a more stable and predictable baseline carbon price, thus reinforcing private-sector willingness to undertake the capital-intensive transformations required for deep decarbonization (Fischer & Fox 2012).

Taken together, these findings indicate that carbon pricing policies—whether cap-and-trade, a direct carbon tax, or some combination thereof—can effectively foster “decoupling,” wherein the economy grows while emissions shrink on a per-dollar basis. Although not every jurisdiction achieves the same pace of carbon-intensity reduction, the broad downward trajectory illustrated in Figure 9 underscores the potential for well-designed market mechanisms to induce a lasting transition away from carbon-intensive production structures.

Figure 9. Change in Carbon intensity of GDP (kg CO₂e per 2021 PPP \$) Before and After ETS Implementation, including carbon tax



Note: The value plotted is changes in the natural log of Carbon intensity of GDP (kg CO₂e per 2021 PPP \$) compared to the period immediately before the ETS was implemented, conditional on carbon tax, natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are robust to heteroskedasticity.

Source: Authors' calculation

Robustness Checks

6.1. Does Carbon Tax confound the impact of ETS?

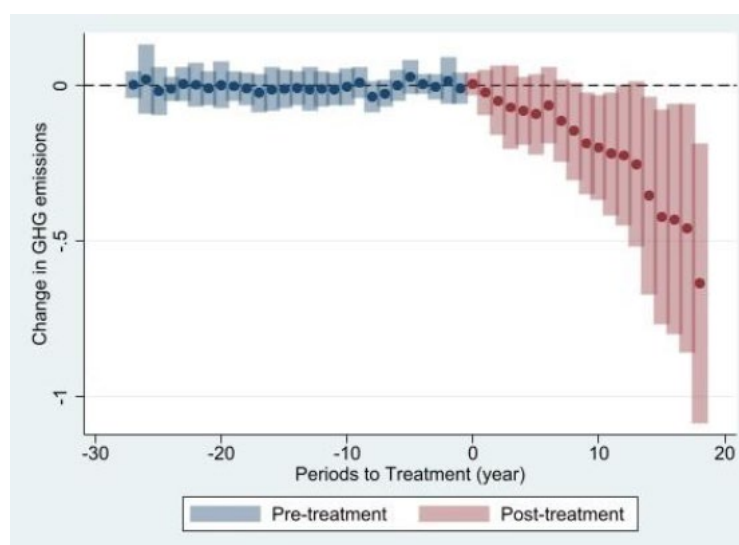
While Emissions Trading Systems (ETS) often feature prominently in the policy mix for curbing greenhouse gas emissions, many jurisdictions also rely on carbon taxes to reinforce price signals and ensure comprehensive sectoral coverage. To disentangle the independent contribution of ETS from the potential confounding influence of concurrent carbon taxation, we augment the baseline event-study specification with a carbon-tax indicator. This approach recognizes that, in practice, governments frequently adopt both instruments in tandem, either to stabilize carbon prices or to exert additional abatement pressure in sectors only partially covered by trading programs (Aldy & Pizer 2015).

Figure 9 depicts the estimated dynamics of GHG emissions before and after ETS introduction when the presence of a carbon tax is explicitly controlled for in the regression. The plotted points illustrate that ETS adoption continues to be associated with a statistically significant negative shift in emissions. In particular, by the tenth year of ETS operation ($T+10$), GHG emissions remain roughly 48.3% lower than they would have been absent a trading system—very close in magnitude to our earlier baseline estimates that did not condition on taxes. Meanwhile, the carbon-tax coefficient itself indicates an additional average reduction of around 9% in emissions across all post-tax years, suggesting that these two policy instruments exert separate and complementary influences on abatement decisions (Fischer & Fox 2012).

Taken together, these results underscore two key insights. First, the robustness of the ETS effect to controlling for carbon taxes lower concerns that our main estimates might be driven primarily by tax-based reductions. Even when introduced in jurisdictions that already levy a carbon tax, the imposition of a trading scheme remain exerting a substantial impact on emissions. Second, the carbon-tax estimates confirm that price-based regulation can indeed bolster decarbonization, especially in market segments or regions where the ETS is less binding or has yet to be fully phased in. Policymakers thus appear to benefit from bundling different types of carbon-pricing policies: while an ETS provides flexibility and taps into cost-effective abatement via trading, a carbon tax can maintain a more predictable price floor and raise stable revenue for environmental and social initiatives (Laing et al. 2013).

In sum, Figure 10 suggests that a policy mix approach—where carbon taxes coexist with ETS—cumulatively drives larger emissions reductions than either instrument would likely achieve in isolation. The use of these overlapping policies highlights how national climate strategies often balance complementary policy goals, including revenue generation, price stability, and broad coverage across heterogeneous emitters.

Figure 10. Change in GHG Emissions Before and After ETS Implementation, including carbon tax



Note: The value plotted is changes in the natural log of emissions compared to the period immediately before the ETS was implemented, conditional on carbon tax, natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are robust to heteroskedasticity.

Source: Authors' calculation

6.2 Does Carbon Leakage explain Emissions Reduction in ETSs' Jurisdictions?

Despite the growing trends, some have raised concerned that ETS may lead to carbon leakage or indeed facilitate the reshuffling of emissions rather than truly reducing emissions. Carbon leakage refers to the phenomenon where firms respond to carbon pricing under an Emissions Trading System (ETS) by relocating production from regulated countries to those with less stringent climate policies. In doing so, businesses can avoid higher carbon costs through trade, potentially undermining the environmental effectiveness of the ETS. Empirical studies have observed increased emissions in non-ETS countries following the introduction of ETS in other jurisdictions, attributed to the offshoring of carbon-intensive production. For instance, the EU's cement and aluminum sectors have experienced rising import levels from non-EU countries. Computable General Equilibrium (CGE) models have estimated leakage rates as high as 20–30% in some sectors.

However, other studies suggest that the actual relocation effect is limited. Despite cost pressures, most firms have remained in ETS countries, often citing productivity and innovation gains that help offset carbon costs. Moreover, structural constraints—such as

capital immobility, labor market frictions, and sunk investment costs—reduce the likelihood of relocation.

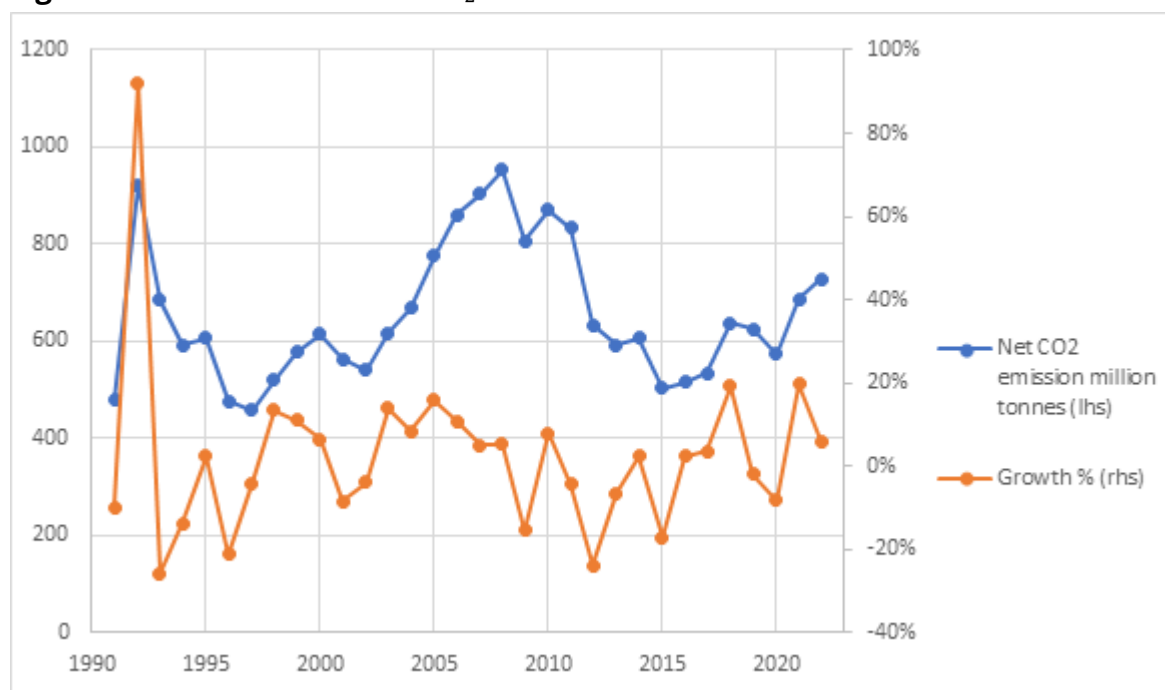
According to the OECD (2024), plant-level data from 140 countries in sectors such as steel, cement, and aluminum show that a US\$1/tCO₂e increase in carbon pricing results in a 1.3% domestic emissions reduction, with approximately 13% of that reduction offset by leakage through trade. Although this leakage is notable, the data suggest that the majority of emissions reductions remain intact, affirming that ETS can be an effective mitigation tool even with some leakage.

Several policy instruments have been introduced to address carbon leakage, including the free allocation of permits, border carbon adjustments (BCAs), and output-based rebates. The effectiveness of these tools varies by sectoral exposure and trade intensity. A prominent example is the EU's Carbon Border Adjustment Mechanism (CBAM), which aims to level the playing field by applying carbon costs to imports from countries with weaker climate regulations. While CBAM is regarded as a vital enhancement to the ETS framework, it also raises concerns regarding trade disputes, administrative complexity, and potential World Trade Organization (WTO) challenges (Hinrich Foundation, 2024).

Using data from the Global Carbon Budget database, we can estimate annual net CO₂ emissions embedded in trade—that is, the net amount of CO₂ imported or exported through traded goods. A positive value indicates that a country or region is a net importer of CO₂ emissions, while a negative value denotes a net exporter. This approach allows researchers to empirically test the carbon leakage hypothesis and assess whether ETS adoption leads to increased embedded emissions via trade. It is important to note that this estimate includes emissions from goods but excludes services, international aviation, and shipping.

Figure 11 below illustrates the EU's net embedded emissions from the 1990s to the present. Emissions increased during the late 1990s but began to decline after the late 2000s. The evidence supporting strong carbon leakage is inconclusive. In fact, net embedded emissions decreased significantly from 2008 to 2015, following the initial phase of the EU ETS (2005–2007). However, there has been a slight upward trend in emissions since 2020, which might be due to other factors such as the post-COVID economic rebound, shifts in global supply chains, increased reliance on carbon-intensive imports.

Figure 11. The EU Annual Net CO₂ Emissions Embedded in Trade



Source: Global Carbon Budget (2025) <https://globalcarbonbudget.org/>

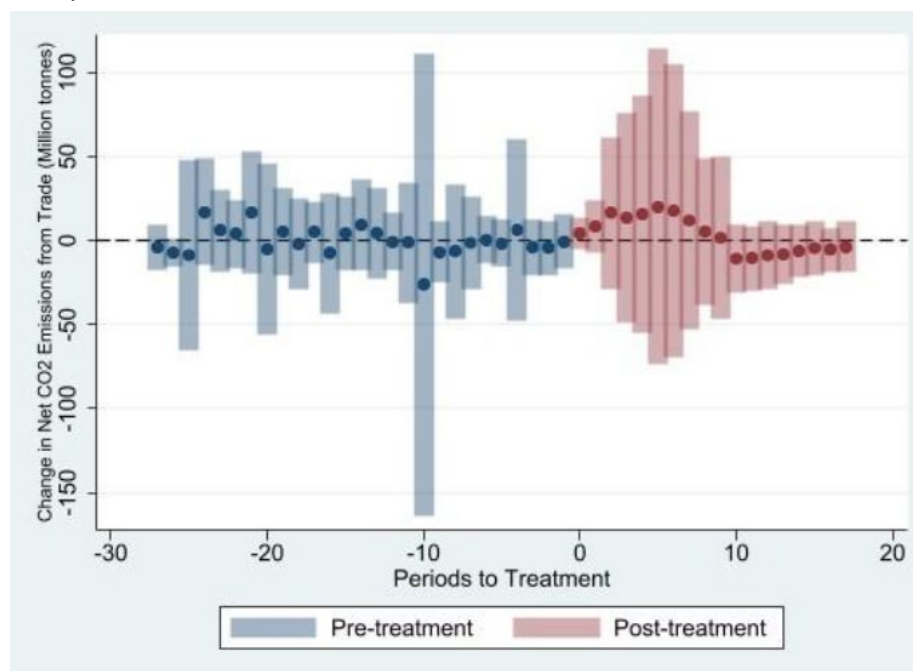
Carbon leakage remains a critical international “spillover,” influencing both the political acceptability and long-term viability of climate policies. This highlights the importance of multilateral coordination and mutual recognition mechanisms to mitigate leakage risks.

To assess the possibility of leakage from trade, we employ the emissions data stemming from trade. Similar as before, we use the timing of the ETS as a policy experiment to see trade-sourced emission trajectories. If emission leakage exists, in which a country relocate emission producing firms to outside of the country, we would observe a positive trend of net trade-embeddeed emissions. That is, the country becomes the net emissions importer. We run a similar specification with equation 1 but now we change the dependent variable as emissions from trade using countries implementing ETS as the treatment group. The estimated coefficients on event year are plotted in Figure 12.

Based on our empirical exercise, we find no strong evidence that net emissions coming from trade significantly increased, statistically, in countries following the implementation of ETS. We find that the point estimates suggest ETS jurisdictions experience a gradual increase in net carbon imports. Within the year of the ETS operationals, the net carbon import reached its peak of 17 million tonnes of CO₂ emissions before it decline. This is consistent with some degree of production shifting to non-regulated regions. However, the wide confidence intervals and lack of statistical significance indicate substantial heterogeneity across countries and time periods. Notably, the trajectory stabilizes and

approaches neutrality beyond the tenth year of implementation, suggesting any initial leakage effects may be transitory rather than structural.

Figure 12. Change in CO2 Emissions from Trade Before and After the ETS Implementation (million tonnes)



Note: The value plotted is changes in the net CO2 emissions from trade in million tonnes compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It include country and year fixed effects. It also includes the 95% confidence intervals where standard errors are robust to heteroskedasticity.

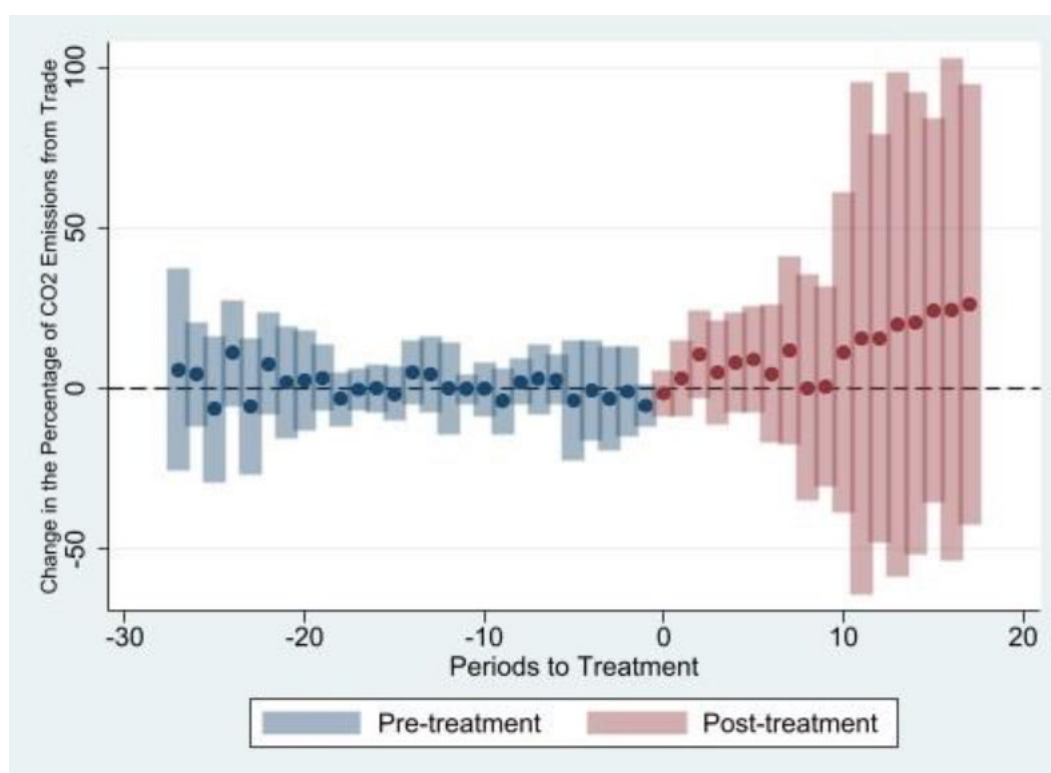
Source: Authors' calculation

The net trade-embedded emissions provide us insight whether countries become net importers (or exporters) following the ETS operational. It does not, however, tell us whether emissions from trade—both exports and imports—are increasing relative to other sources of emissions. To have that insight, we run the regression of specification 1 in which the share of emissions from trade as the dependent variable. The estimated coefficients for each period are plotted in figure 13.

Figure 13 examines whether trade-embedded emissions increase as a proportion of total national emissions following ETS adoption. While the point estimates suggest a positive trend in the share of trade-embedded emissions over time, the results are characterized by wide confidence intervals that suggest the effects statistically insignificant at conventional levels.

The estimated coefficients indicate a potential increase in trade-embedded emissions relative to total emissions in the years following ETS implementation. However, it is clear that there is wide heterogeneity as it is shown by the wide standard errors, providing no clear evidence about systematic shifts in the composition of national emission profiles toward trade-embedded sources.

Figure 13. Change in the share of CO2 Emissions from Trade Before and After the ETS Implementation (percentage points)



Note: The value plotted is changes in the percentage of CO2 emissions from trade to total emissions compared to the period immediately before the ETS was implemented, conditional on natural log of real GDP per capita and its square, the percent of value added to GDP in agriculture and industry sectors, and the share of trade to GDP. It includes country and year fixed effects. It also includes the 95% confidence intervals where standard errors are robust to heteroskedasticity.

Source: Authors' calculation

The consistent lack of statistical significance across both absolute leakage measures (Figure 12) and relative emission share changes (Figure 13) suggests that concerns about systematic carbon leakage may be overestimated, at least at the aggregate national level. Instead, this supports the argument that the effective emissions trading programs may not necessarily drive the offshoring of emissions across jurisdictions, particularly when other nations pursue their own climate initiatives (Aldy & Pizer, 2015; Ellerman et al.,

2016). These findings also align with studies on leakage risks in cap-and-trade systems that highlight the importance of allowance allocation, monitoring frameworks, and cross-border policy coordination for improving the effectiveness of ETS (Martin et al., 2016; Hintermann, Peterson, & Rickels, 2016).

Conclusions

This paper provides robust evidence on the effectiveness of Emissions Trading Systems in reducing greenhouse gas emissions across multiple jurisdictions and sectors. Using the Callaway and Sant'Anna (2020) difference-in-differences framework with staggered treatment adoption, we overcome methodological limitations that relied on two-way fixed effects models potentially biased by heterogeneous treatment effects.

Our findings demonstrate that ETS implementation leads to substantial and statistically significant emissions reductions, with average declines of 19 percent across all post-implementation periods. The sectoral analysis reveals particularly pronounced effects in power generation (30.2 percent) and industrial combustion (27.9 percent), while transportation shows more modest but still significant decreases (8.4 percent). Importantly, these effects strengthen over time, with emissions declining by approximately 23.1 percent after ten years of implementation. The effectiveness varies across implementation cohorts, with the EU ETS cohort achieving the largest reductions (28.9 percent), suggesting the importance of system design and implementation details.

These results have several policy implications. First, they provide strong evidence that market-based mechanisms can effectively reduce emissions when properly designed and implemented. Second, the heterogeneity in sectoral responses suggests that policymakers should consider sector-specific characteristics when designing emissions trading programs. Third, the increasing effectiveness over time indicates that learning effects and policy adjustments can enhance ETS performance, highlighting the importance of flexibility and adaptive management in climate policy.

Our robustness checks demonstrate that ETS effects remain significant when controlling for concurrent carbon taxation, suggesting these instruments provide complementary rather than redundant price signals. Furthermore, our analysis of carbon intensity reveals that ETS implementation accelerates transitions toward less carbon-intensive production structures, addressing concerns about potential trade-offs between emissions reductions and economic growth.

While our study provides evidence on ETS effectiveness, several questions remain for future research. First, the heterogeneous effects across implementation cohorts suggest the need for more detailed analysis of specific design features that enhance effectiveness. Second, potential interaction effects between ETS and other climate policies beyond carbon taxation merit closer examination.

Overall, our findings suggest that well-designed emissions trading systems can play a central role in climate policy. As countries continue to enhance climate ambition under the Paris Agreement framework, these results provide valuable guidance for policymakers considering or refining market-based approaches to emissions reduction. The substantial emissions decreases observed, particularly in later years of implementation, indicate that ETS can deliver meaningful contributions to global climate mitigation efforts when designed with appropriate stringency, coverage, and complementary policies.

References

- Aldy, J. E., & Pizer, W. A. (2015). The competitiveness impacts of climate change mitigation policies. *Journal of the Association of Environmental and Resource Economists*, 2(4), 565-595.
- Bai, J. and Ru, H. (2024). Carbon emissions trading and environmental protection: International evidence. *Management Science*, 70(7), 4593-4603.
- Borghesi, S., & Montini, M. (2022). The European Emissions Trading System: A review of the first two decades. *Environmental Economics and Policy Studies*, 24(1), 1-26.
- Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking Emission Trading to Environmental Innovation: Evidence from the Italian Manufacturing Industry. *Research Policy*, 44(3), 669-683.
- Borusyak, K., & Jaravel, X. (2017). *Revisiting event study designs*. Working Paper.
- Callaway, B., & Sant'Anna, P. H. (2020). *Difference-in-differences with multiple time periods*. Working Paper.
- de Chaisemartin, C., & D'Haultfœuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review*, 110(9), 2964-2996.
- Dechezleprêtre, A., & Sato, M. (2017). The Impacts of Environmental Regulations on Competitiveness. *Review of Environmental Economics and Policy*, 11(2), 183-206.
- Ellerman, A. D., & Buchner, B. K. (2008). Over-allocation or abatement? A preliminary analysis of the EU ETS based on the 2005-06 emissions data. *Environmental and Resource Economics*, 41(2), 267-287.
- Ellerman, A. D., Convery, F. J., & de Perthuis, C. (2010). *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge University Press.
- Ellerman, A. D., Marcantonini, C., & Zaklan, A. (2016). The European Union Emissions Trading System: Ten years and counting. *Review of Environmental Economics and Policy*, 10(1), 89-107.
- Fischer, C., & Fox, A. K. (2012). Comparing Policies to Combat Emissions Leakage: Border Carbon Adjustments versus Rebates. *Journal of Environmental Economics and Management*, 64(2), 199-216.
- Fowlie, M., Holland, S. P., & Mansur, E. T. (2012). What do emissions markets deliver and to whom? Evidence from Southern California's NOx trading program. *American Economic Review*, 102(2), 965-993.
- Fowlie, M., Reguant, M., & Ryan, S. P. (2016). Market-based emissions regulation and industry dynamics. *Journal of Political Economy*, 124(1), 249-302.
- Global Carbon Budget. (2025). Data available at <https://globalcarbonbudget.org/>.
- Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, 225(2), 254-277.

- Hinrich Foundation. (2024). *The EU's Carbon Border Adjustment Mechanism (CBAM): Implications for global trade*. Research Report.
- Hintermann, B. (2010). Allowance Price Drivers in the First Phase of the EU ETS. *Journal of Environmental Economics and Management*, 59(1), 43-56.
- Hintermann, B., Peterson, S., & Rickels, W. (2016). Price and market behavior in Phase II of the EU ETS: A review of the literature. *Review of Environmental Economics and Policy*, 10(1), 108-128.
- Koch, N., Fuss, S., Grosjean, G., & Edenhofer, O. (2014). Causes of the EU ETS price collapse: A retrospective analysis. *Energy Policy*, 73, 112-121.
- Laing, T., Sato, M., Grubb, M., & Comberty, C. (2013). *Assessing the Effectiveness of the EU Emissions Trading System*. Centre for Climate Change Economics and Policy Working Paper No. 126, Grantham Research Institute on Climate Change and the Environment.
- Liu, L., & Zhang, Z. (2023). Evaluating China's national emissions trading system: Market performance and future challenges. *Energy Economics*, 119, 106529.
- Martin, R., Muûls, M., & Wagner, U. J. (2016). The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years?. *Review of Environmental Economics and Policy*, 10(1), 129-148.
- Martin, R., Muuls, M., de Preux, L. B., & Wagner, U. J. (2016). Industry Compensation Under Relocation Risk: A Firm-level Analysis of the EU Emissions Trading Scheme. *Journal of Public Economics*, 136, 1-14.
- Murray, B. C., Maniloff, P., & Murray, E. (2014). Why have greenhouse emissions in RGGI states declined? An economic attribution to economic, energy market, and policy factors. *Energy Economics*, 44, 81-89.
- Narassimhan, E., Gallagher, K. S., Koester, S., & Alejo, J. R. (2018). Carbon pricing in practice: a review of existing policies. *Climate Policy*, 18(8), 967-991.
- OECD. (2024). *Quantifying the effect of carbon pricing on firm-level emissions and competitiveness*. OECD Environment Policy Papers, No. 36, OECD Publishing, Paris.
- Petrack, S., & Wagner, U. J. (2014). The Impact of Carbon Trading on Industry: Evidence from German Manufacturing Firms. *Journal of Environmental Economics and Management*, 68(1), 87-100.
- Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, 225(2), 175-199.
- Tietenberg, T. H. (2006). *Emissions Trading: Principles and Practice*. Resources for the Future Press.
- Victor, D. G. (2011). *Global Warming Gridlock: Creating More Effective Strategies for Protecting the Planet*. Cambridge, UK: Cambridge University Press.

Wara, M. (2007). Is the Global Carbon Market Working? *Nature*, 445(7128), 595-596.

Wara, M., & Victor, D. (2008). *A Realistic Policy on International Carbon Offsets*. Program on Energy and Sustainable Development, Working Paper #74, Stanford University.

World Bank. (2022). *State and Trends of Carbon Pricing 2022*. Washington, DC: World Bank.

World Bank. (2024). *State and Trends of Carbon Pricing 2024*. Washington, DC: World Bank.

Appendix

Table A.1 Impact of ETS on Emissions: Dynamic Effects

Variables	GHG	CO2	CO2 Industrial Combustion	CO2 Industrial Process	CO2 Power	CO2 Transportation
Pre-treatment Average	-0.002 (0.004)	0 (0.005)	-0.012* (0.007)	0.002 (0.006)	0.007 (0.008)	0.013** (0.005)
Post-treatment Average	-0.190*** (0.034)	-0.235*** (0.036)	-0.279*** (0.079)	-0.137*** (0.039)	-0.302*** (0.038)	-0.084*** (0.028)
T-15	-0.007 (0.016)	0.004 (0.020)	-0.029 (0.031)	-0.004 (0.024)	0.021 (0.024)	0.015 (0.016)
T-14	0.01 (0.012)	0.007 (0.013)	-0.004 (0.033)	0.092 (0.071)	-0.008 (0.022)	0.015 (0.026)
T-13	-0.007 (0.019)	-0.001 (0.018)	-0.016 (0.046)	-0.027 (0.033)	0.066 (0.049)	0.051 (0.040)
T-12	-0.004 (0.011)	0.005 (0.012)	-0.004 (0.023)	-0.016 (0.018)	0.013 (0.033)	0.015 (0.019)
T-11	0.004 (0.010)	-0.004 (0.013)	-0.063** (0.027)	-0.013 (0.016)	0.008 (0.024)	0.006 (0.017)
T-10	0.004 (0.011)	0.004 (0.014)	-0.005 (0.036)	-0.017 (0.025)	0.005 (0.021)	0.002 (0.012)
T-9	0.01 (0.013)	0.009 (0.013)	-0.009 (0.018)	-0.013 (0.028)	0.016 (0.021)	0.016 (0.014)
T-8	-0.031*** (0.011)	-0.034*** (0.012)	-0.004 (0.027)	0 (0.015)	-0.039** (0.017)	0.003 (0.010)
T-7	-0.021* (0.011)	-0.018* (0.011)	-0.018 (0.016)	-0.003 (0.014)	0.012 (0.021)	0.006 (0.012)
T-6	0.005 (0.011)	0.004 (0.014)	-0.005 (0.018)	-0.007 (0.008)	-0.004 (0.025)	0.020** (0.010)
T-5	0.014 (0.016)	0.027 (0.019)	0.03 (0.035)	0.018 (0.012)	-0.011 (0.022)	0.015 (0.013)
T-4	0.005 (0.008)	0.008 (0.009)	-0.015 (0.016)	0.005 (0.022)	0.018 (0.013)	0.017* (0.009)
T-3	-0.007 (0.008)	-0.017* (0.009)	-0.040** (0.019)	-0.015 (0.010)	0 (0.019)	-0.002 (0.008)
T-2	0.019 (0.022)	0.023 (0.023)	0.015 (0.015)	0.012 (0.018)	0.023 (0.021)	0.013 (0.015)
T-1	-0.018** (0.009)	-0.015 (0.011)	-0.007 (0.014)	0.024** (0.012)	-0.019 (0.015)	0.009 (0.012)
T+0	0.002 (0.008)	0 (0.010)	-0.011 (0.010)	-0.01 (0.012)	-0.005 (0.019)	0.019** (0.009)
T+1	-0.029* (0.017)	-0.044** (0.018)	-0.046* (0.024)	-0.007 (0.014)	-0.056** (0.025)	0.014 (0.013)

T+2	-0.065** (0.027)	-0.084*** (0.028)	-0.086** (0.034)	-0.01 (0.025)	-0.087*** (0.027)	0.005 (0.021)
T+3	-0.092*** (0.032)	-0.111*** (0.034)	-0.132*** (0.047)	-0.029 (0.028)	-0.123*** (0.033)	-0.02 (0.024)
T+4	-0.103*** (0.026)	-0.131*** (0.030)	-0.215*** (0.058)	-0.105*** (0.031)	-0.119*** (0.032)	-0.043* (0.023)
T+5	-0.112*** (0.032)	-0.143*** (0.033)	-0.216*** (0.077)	-0.102*** (0.038)	-0.134*** (0.033)	-0.050* (0.029)
T+6	-0.087*** (0.030)	-0.125*** (0.030)	-0.201*** (0.047)	-0.119** (0.050)	-0.168*** (0.035)	-0.028 (0.028)
T+7	-0.146*** (0.033)	-0.195*** (0.033)	-0.249*** (0.054)	-0.128** (0.051)	-0.241*** (0.041)	-0.073** (0.035)
T+8	-0.179*** (0.036)	-0.234*** (0.037)	-0.372*** (0.124)	-0.136** (0.055)	-0.283*** (0.048)	-0.116*** (0.039)
T+9	-0.217*** (0.040)	-0.280*** (0.042)	-0.387*** (0.127)	-0.159*** (0.050)	-0.352*** (0.051)	-0.131*** (0.039)
T+10	-0.231*** (0.037)	-0.292*** (0.039)	-0.373*** (0.121)	-0.171*** (0.054)	-0.378*** (0.057)	-0.108*** (0.037)
T+11	-0.262*** (0.046)	-0.322*** (0.049)	-0.378*** (0.124)	-0.220*** (0.061)	-0.457*** (0.056)	-0.133*** (0.039)
T+12	-0.274*** (0.056)	-0.332*** (0.058)	-0.403*** (0.137)	-0.186*** (0.059)	-0.456*** (0.062)	-0.128*** (0.043)
T+13	-0.314*** (0.070)	-0.375*** (0.074)	-0.393*** (0.130)	-0.234*** (0.060)	-0.507*** (0.075)	-0.138*** (0.049)
T+14	-0.429*** (0.085)	-0.512*** (0.092)	-0.469*** (0.145)	-0.264*** (0.065)	-0.676*** (0.095)	-0.173*** (0.061)
T+15	-0.504*** (0.078)	-0.577*** (0.100)	-0.534*** (0.176)	-0.307*** (0.073)	-0.791*** (0.121)	-0.234*** (0.059)

Table A.2 Impact of ETS on Emissions: Calendar Effects

Variables	GHG	CO2	CO2 Industrial Combustion	CO2 Industrial Process	CO2 Power	CO2 Transportation
CAverage	-0.199*** (0.035)	-0.242*** (0.039)	-0.266*** (0.070)	-0.136*** (0.038)	-0.306*** (0.043)	-0.088*** (0.027)
2005	-0.014 (0.013)	-0.013 (0.015)	-0.011 (0.014)	-0.029** (0.014)	-0.02 (0.024)	0.018 (0.012)
2006	-0.061** (0.027)	-0.071*** (0.026)	-0.059* (0.031)	-0.025 (0.017)	-0.055** (0.025)	-0.004 (0.020)
2007	-0.090** (0.038)	-0.106*** (0.038)	-0.075** (0.030)	-0.004 (0.023)	-0.085*** (0.032)	-0.009 (0.029)
2008	-0.126*** (0.040)	-0.143*** (0.041)	-0.167*** (0.046)	-0.050* (0.029)	-0.140*** (0.036)	-0.044 (0.030)
2009	-0.163*** (0.025)	-0.196*** (0.028)	-0.317*** (0.062)	-0.191*** (0.030)	-0.190*** (0.031)	-0.078*** (0.023)
2010	-0.163*** (0.034)	-0.195*** (0.034)	-0.310*** (0.091)	-0.181*** (0.039)	-0.178*** (0.037)	-0.111*** (0.028)
2011	-0.093*** (0.032)	-0.125*** (0.029)	-0.222*** (0.041)	-0.190*** (0.054)	-0.157*** (0.037)	-0.072*** (0.027)
2012	-0.172*** (0.037)	-0.221*** (0.034)	-0.285*** (0.048)	-0.218*** (0.055)	-0.242*** (0.040)	-0.144*** (0.033)
2013	-0.170*** (0.037)	-0.223*** (0.039)	-0.362*** (0.123)	-0.171*** (0.050)	-0.267*** (0.041)	-0.145*** (0.032)
2014	-0.205*** (0.040)	-0.267*** (0.043)	-0.382*** (0.127)	-0.160*** (0.048)	-0.336*** (0.048)	-0.147*** (0.035)
2015	-0.211*** (0.037)	-0.269*** (0.039)	-0.369*** (0.115)	-0.164*** (0.052)	-0.363*** (0.050)	-0.115*** (0.034)
2016	-0.194*** (0.040)	-0.243*** (0.043)	-0.301*** (0.097)	-0.150*** (0.051)	-0.323*** (0.055)	-0.085*** (0.033)
2017	-0.195*** (0.046)	-0.241*** (0.048)	-0.301*** (0.106)	-0.127*** (0.045)	-0.325*** (0.058)	-0.065* (0.037)
2018	-0.212*** (0.056)	-0.259*** (0.060)	-0.276*** (0.099)	-0.148*** (0.048)	-0.355*** (0.067)	-0.066* (0.039)
2019	-0.272*** (0.066)	-0.330*** (0.074)	-0.309*** (0.110)	-0.140*** (0.052)	-0.448*** (0.082)	-0.094** (0.044)
2020	-0.326*** (0.067)	-0.379*** (0.083)	-0.332*** (0.129)	-0.154** (0.063)	-0.540*** (0.100)	-0.130*** (0.045)
2021	-0.313*** (0.070)	-0.358*** (0.087)	-0.294*** (0.106)	-0.134** (0.057)	-0.493*** (0.102)	-0.105** (0.043)
2022	-0.350*** (0.070)	-0.405*** (0.086)	-0.372*** (0.106)	-0.193*** (0.057)	-0.554*** (0.107)	-0.125*** (0.046)
2023	-0.457*** (0.068)	-0.547*** (0.074)	-0.316*** (0.057)	-0.155*** (0.052)	-0.747*** (0.104)	-0.157*** (0.048)

Table A.3 Impact of ETS on Emissions: Group/Cohort Effects

	GHG	CO2	CO2 Industrial Combustion	CO2 Industrial Process	CO2 Power	CO2 Transportation
GAverage	-0.157*** (0.024)	-0.197*** (0.027)	-0.212*** (0.055)	-0.098*** (0.028)	-0.264*** (0.032)	-0.058*** (0.019)
G2005	-0.289*** (0.043)	-0.342*** (0.048)	-0.354*** (0.097)	-0.203*** (0.049)	-0.420*** (0.053)	-0.153*** (0.034)
G2007	-0.186*** (0.054)	-0.241*** (0.079)	-0.376*** (0.111)	-0.238*** (0.035)	-0.309*** (0.096)	-0.015 (0.056)
G2008	-0.028 (0.028)	-0.046 (0.030)	0.016 (0.114)	0.054 (0.115)	-0.311*** (0.094)	0.003 (0.016)
G2009	-0.066** (0.028)	-0.068** (0.033)	-0.089* (0.051)	0.112* (0.063)	-0.253** (0.121)	0 (0.031)
G2013	-0.016 (0.066)	-0.039 (0.066)	-0.138 (0.140)	0.126* (0.070)	-0.005 (0.114)	0.144** (0.064)
G2015	-0.027* (0.015)	-0.014 (0.017)	0.043 (0.053)	0.144*** (0.013)	-0.008 (0.027)	0.094*** (0.021)
G2016	0.002 (0.052)	-0.035 (0.064)	-0.011 (0.103)	0.023 (0.064)	-0.068 (0.067)	0.061** (0.028)
G2017	0.196*** (0.025)	0.277*** (0.029)	0.613*** (0.031)	0.179*** (0.040)	0.214*** (0.037)	-0.042 (0.045)
G2021	-0.015 (0.012)	-0.037 (0.024)	-0.118** (0.059)	-0.017 (0.034)	0.023 (0.071)	-0.015 (0.039)
G2022	0.021 (0.035)	-0.057*** (0.021)	-0.002 (0.022)	-0.048*** (0.012)	-0.319 (0.205)	0.014 (0.032)
G2023	0.027*** (0.007)	0.017** (0.007)	-0.008 (0.007)	-0.021*** (0.006)	0.033 (0.020)	0.043 (0.027)

Table A.4 Impact of ETS on Emissions controlling for carbon tax: Dynamic Effects

Variables	GHG	CO2	CO2 Industrial Combustion	CO2 Industrial Process	CO2 Power	CO2 Transportation
Pre-treatment Average	-0.004 (0.005)	0 (0.005)	-0.016** (0.007)	0.003 (0.006)	0.008 (0.007)	0.013** (0.005)
Post-treatment Average	-0.154*** (0.034)	-0.208*** (0.035)	-0.194*** (0.075)	-0.094** (0.045)	-0.397*** (0.058)	-0.058** (0.029)
T-15	-0.01 (0.015)	0.003 (0.020)	-0.024 (0.030)	-0.004 (0.023)	0.047 (0.034)	0.018 (0.016)
T-14	-0.006 (0.013)	-0.005 (0.014)	-0.001 (0.029)	0.023 (0.023)	0.016 (0.026)	0.015 (0.024)
T-13	-0.01 (0.020)	0.003 (0.020)	-0.014 (0.043)	0.014 (0.021)	0.035 (0.040)	0.064* (0.038)
T-12	-0.009 (0.015)	0.006 (0.013)	-0.01 (0.027)	-0.026 (0.017)	0.007 (0.034)	0.01 (0.018)
T-11	-0.01 (0.014)	-0.012 (0.013)	-0.079** (0.033)	-0.008 (0.015)	0.015 (0.027)	0 (0.019)
T-10	-0.002 (0.014)	0.001 (0.015)	-0.005 (0.038)	-0.017 (0.026)	0.007 (0.021)	0.004 (0.013)
T-9	0.011 (0.013)	0.012 (0.014)	-0.011 (0.019)	-0.007 (0.029)	0.013 (0.022)	0.014 (0.015)
T-8	-0.035*** (0.012)	-0.041*** (0.013)	-0.014 (0.025)	0.002 (0.013)	-0.039** (0.017)	-0.001 (0.011)
T-7	-0.024** (0.011)	-0.024** (0.012)	-0.033* (0.017)	-0.001 (0.014)	0.002 (0.022)	-0.001 (0.011)
T-6	0.002 (0.013)	0.002 (0.017)	-0.012 (0.018)	-0.007 (0.009)	-0.004 (0.027)	0.014 (0.010)
T-5	0.028** (0.014)	0.044*** (0.017)	0.035 (0.049)	0.021 (0.013)	-0.008 (0.022)	0.027** (0.012)
T-4	0.006 (0.008)	0.008 (0.009)	-0.009 (0.018)	0.005 (0.019)	0.002 (0.015)	0.019** (0.010)
T-3	-0.003 (0.010)	-0.015 (0.010)	-0.031 (0.020)	-0.008 (0.010)	-0.003 (0.019)	0.002 (0.008)
T-2	0.017 (0.019)	0.018 (0.020)	-0.014 (0.020)	0.017 (0.023)	0.018 (0.020)	0.004 (0.015)
T-1	-0.008 (0.014)	-0.002 (0.016)	-0.016 (0.016)	0.036*** (0.011)	0.012 (0.018)	0.007 (0.013)
T+0	0.006 (0.009)	0.004 (0.010)	0.004 (0.013)	0.008 (0.013)	-0.001 (0.019)	0.020** (0.009)
T+1	-0.02 (0.018)	-0.039** (0.018)	-0.014 (0.031)	0.009 (0.017)	-0.052** (0.026)	0.019 (0.014)
T+2	-0.048* (0.027)	-0.065** (0.028)	-0.037 (0.042)	0.003 (0.028)	-0.091*** (0.028)	0.017 (0.021)

T+3	-0.069** (0.032)	-0.091*** (0.033)	-0.059 (0.053)	-0.021 (0.033)	-0.112*** (0.033)	0.003 (0.026)
T+4	-0.079*** (0.027)	-0.110*** (0.030)	-0.115* (0.064)	-0.065* (0.037)	-0.205*** (0.054)	-0.011 (0.028)
T+5	-0.091*** (0.032)	-0.125*** (0.033)	-0.156** (0.072)	-0.063 (0.043)	-0.263*** (0.059)	-0.03 (0.030)
T+6	-0.063** (0.028)	-0.102*** (0.031)	-0.139** (0.064)	-0.067 (0.053)	-0.284*** (0.058)	-0.017 (0.030)
T+7	-0.113*** (0.032)	-0.171*** (0.032)	-0.201*** (0.058)	-0.091* (0.053)	-0.332*** (0.058)	-0.04 (0.036)
T+8	-0.144*** (0.038)	-0.208*** (0.039)	-0.274*** (0.104)	-0.098 (0.061)	-0.402*** (0.067)	-0.091** (0.038)
T+9	-0.185*** (0.039)	-0.257*** (0.041)	-0.282** (0.111)	-0.104* (0.057)	-0.482*** (0.077)	-0.115*** (0.039)
T+10	-0.198*** (0.038)	-0.273*** (0.040)	-0.255** (0.111)	-0.117** (0.059)	-0.525*** (0.089)	-0.098** (0.039)
T+11	-0.218*** (0.047)	-0.296*** (0.051)	-0.238** (0.116)	-0.166*** (0.063)	-0.591*** (0.084)	-0.104** (0.044)
T+12	-0.223*** (0.054)	-0.300*** (0.055)	-0.268** (0.123)	-0.136** (0.063)	-0.592*** (0.089)	-0.081* (0.049)
T+13	-0.251*** (0.064)	-0.329*** (0.067)	-0.288** (0.112)	-0.170** (0.067)	-0.649*** (0.090)	-0.092* (0.051)
T+14	-0.352*** (0.079)	-0.453*** (0.084)	-0.360*** (0.120)	-0.188** (0.075)	-0.844*** (0.121)	-0.120** (0.060)
T+15	-0.422*** (0.085)	-0.509*** (0.102)	-0.424*** (0.161)	-0.233*** (0.087)	-0.925*** (0.151)	-0.183*** (0.068)



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