NBER WORKING PAPER SERIES

CARBON EMISSIONS TRADING AND ENVIRONMENTAL PROTECTION: INTERNATIONAL EVIDENCE

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Working Paper 30587
http://www.nber.org/papers/w30587

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 2022

We thank the financial support from the Nanyang Technological University. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Carbon Emissions Trading and Environmental Protection: International Evidence
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NBER Working Paper No. 30587
October 2022
JEL No. E62,H23,Q54,Q58

ABSTRACT

We study how the implementation of emissions trading systems (ETS) impacts emissions reductions and the usage of renewable energy using a panel sample of the largest 100 countries worldwide. Exploiting the cross-country variations in ETS implementations, we show that ETS adoption materially reduced greenhouse gas (carbon dioxide) emissions by 12.1% (18.1%). Moreover, ETSs reduced overall emissions by cutting fossil fuel usage, such as coal, by 23.70% while boosting the usage of renewable energy by 61.59%, on average. In contrast, the introduction of carbon taxes has a less effective impact on emissions reduction and fails to boost the usage of renewable energy.

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1. Introduction

Climate change is the defining challenge in the past few decades. The devastating impacts of climate change are more visible recently, with wildfires ravaging Australia, sea levels rising at an alarming rate, and record temperatures.[1] Climate change is a crucial risk for the global economy and hence arises at the top of government policy agendas worldwide. The main cause of climate change is greenhouse gas (GHG) emissions, mainly carbon dioxide (CO2). Therefore, most existing and proposed policies involve carbon pricing instruments to reduce emissions such as carbon tax and emissions trading system (ETS). As of 2021, these carbon pricing instruments cover about 23 percent of global GHG emissions.[2]

Despite this prominance, questions remain about how carbon pricing works in practice, in particular whether the market-based emissions trading programs can truly reduce carbon emissions. Emissions trading, also known as cap and trade, works by setting a total cap on emissions, issuing emission permits to firms, and allowing firms to trade the permits as commodities. As a result, it can raise production costs, lower the competitiveness of high-emission firms, and accelerate investments into low-carbon energy sources.

While some policymakers and economists believe that ETSs are the most cost-effective way to reduce emissions (e.g., European Commission, 2003; Keohane, 2009; Bushnell et al., 2013; Schmalensee and Stavins, 2017), empirical evidence is not so clear. Many studies have shown the ineffectiveness of ETSs in reducing emissions. Kill et al. (2010) argue that since low-emission groups sell their permits to the highest bidder, ETSs redistribute emission allowances but do not reduce the system's total emissions. Betz et al. (2006) show that giving free allowances created inefficient incentives across industry sectors in the emission markets during Phase I of EU ETS. Ellerman et al. (2010) and Laing et al. (2013) point out that political obstacles stymie attempts to generate an effective carbon price in EU ETS. More recently, Bartram et al. (2022) and Ben-David et al. (2021) document that localized carbon instruments to mitigate climate risk can have unintended consequences since firms make regulatory arbitrage which leads to emission leakage to under-regulated areas. Meanwhile, a parallel line of research shows that carbon taxes can

[1] See for example, Lin, Schmid and Weisbach (2022) for climate changes impact on electric utilities' investments and Chang and Kajackaite (2019) for temperature's effects on cognitive performance.
[2] Source: World Bank carbon pricing dashboard, https://carbonpricingdashboard.worldbank.org.

effectively reduce emissions (e.g., Andersson, 2019; Martin et al., 2014; Metcalf, 2019) and tend to work better than ETSs (e.g., Ellerman et al., 2016).

The above papers and most of the carbon pricing literature focus only on a specific geographical region or, at most, the spillover effect to adjacent regions.[3] However, addressing climate change is a global problem. To appraise the global impact of local ETS policies, we need to create an international dataset and exploit the staggered implementations of ETS policies.

In this paper, we collect ETS policy events from the 100 largest countries by GDP as of 2020 and provide the first *international* study on the effectiveness of ETSs. Among the top 100 countries, 34 have launched national or regional ETSs and 26 have implemented carbon taxes—including 17 countries that have implemented both—during our 2000–2020 sample period (Table 1). Employing a staggered difference-in-differences (DID) method, we investigate the impact of ETS implementations on emissions and the usage of renewable versus fossil fuel energy. We also compare the effects of carbon trading versus carbon tax.

First, we find that the ETS implementations substantially reduced emissions. After launching an ETS, countries reduced the overall GHG (CO2) emissions by 12.1% (18.1%), on average, which is economically substantial. To gauge the economic effect of this result, we compare the coefficient estimate to the standard deviation of emissions after controlling for country and year fixed effects and find that the ETS policy shock explains about 10.2% of the variation of CO2 emissions.

Using a dynamic setup, we further find that changes in emissions did not happen before the ETS policy shock. Also, the impact of ETS implementations materialized quickly from the second year and continued to grow for the next ten years. This supports the parallel trend assumption underlying the DID analyses. Moreover, these results are robust to controlling for time-varying country characteristics that potentially affect emissions. For example, a country tends to have higher emissions if it has a larger GDP, a larger population, a higher proportion of GDP contributed by the manufacturing and agriculture sectors, or a lower proportion of GDP contributed by the service sector. The results are also robust when considering the GHG emissions *per capita*, with an estimated reduction of 10.1% after ETS adoption.

[3] For example, Ellerman et al. (2010), Koch and Mama (2019), and Herweg (2020) study the European Union ETS; Schmalensee and Stavins (2017), and Fowlie et al. (2012) study several regional markets in the U.S., for example, California's regional clean air incentives market (RECLAIM) and AB-32 cap-and-trade system, and the Regional Greenhouse Gas Initiative (RGGI) in the Northeast; FOEN (2016) studies Switzerland's ETS; and more recent studies like Guo et al (2021) focus on China, the largest carbon market in the world.

Second, we show that emissions reduction is associated with increased usage of renewable energy. After implementing ETSs, electricity produced from high-carbon fossil fuels such as coal dropped significantly by 23.70%. In contrast, electricity produced from low-carbon energy such as hydropower (flowing water) and other renewable energy (e.g., geothermal, solar, tides, wind, biomass, and biofuels) increased by 5.04% and 61.59%, respectively. Like the emissions reduction pattern before the ETS shock, we do not find any significant pre-trends in the usage of renewable energy. The literature shows that carbon pricing instruments incentivize carbon-saving innovations (Jung et al., 1996; Porter and Van der Linde, 1995; Dechezleprêtre et al., 2016), but, to the best of our knowledge, our paper is the first to provide direct evidence of the increasing usage of renewable energy due to an ETS policy.

The impact of ETSs on emission reduction and the usage of clean energy occurs not only upon initial implementation but also when ETSs adjust the emission cap (mainly at the annual base) years after the adoption. We find that if ETSs lower the emission allowance by 50%, CO2 emissions fall approximately 3.95%, and electricity produced by renewable energies increases significantly, by 59.27%.

Lastly, we add novel evidence to the policy debate on ETSs by comparing the effects of carbon trading versus carbon tax, another important climate policy advocated by policymakers and economists (Metcalf, 2019; Bushnell et al., 2013). In our sample, 17 countries implemented both an ETS and a carbon tax. Because the co-existence of two climate policies may exaggerate the ETS impact due to the confounding effect, we repeat the analysis in a subsample of countries that levied a carbon tax before adopting an ETS. We show that ETSs have significant power in explaining the change in emissions, whereas carbon taxes do not. In a separate regression that includes only the indicator of carbon tax implementations, we find that countries experienced a reduction in GHG emissions after enforcing carbon taxes. However, such emissions reduction also occurred years before the tax shock, making it difficult to conclude that levying a carbon tax leads to reduced emissions.

Most importantly, we find that carbon taxes have a negligible impact on the usage of renewable energy. In contrast, ETSs can effectively boost renewable energy usage and simultaneously reduce overall emissions. The finding is robust if we test the solo impact of carbon taxes without including the indicator of the ETS inception. One possible explanation is that ETSs set a cap on total emissions and companies have to switch to low-emission energy sources, whereas carbon taxes directly affect the carbon price, hoping to reduce the level of emissions which, as we know, is uncertain. Also, the cost of carbon taxes can be partially passed through to customers, though we do not have direct evidence of pass-through.

Our paper contributes to the literature in three dimensions. First, we provide the first international quantitative study on the effectiveness of ETSs. Using the staggered difference-in-difference method, we estimate not the differences in emissions for a given country implementing ETS, but rather the differences between two differences for countries implementing ETSs vs. those not implementing at a given year. Thus, we estimate the global impact of ETS implementations for the largest 100 countries in our sample.

Second, we identify the channel of the ETS effectiveness. We provide direct evidence that electricity was produced more from renewable energy and far less from fossil fuel energy after the ETS implementations. Third, we add novel evidence to the policy debates on ETSs versus alternative policies such as carbon taxes. The literature is largely divided on which climate policy is more effective. Some support carbon taxes (Metcalf, 2019; Bushnell et al., 2013, among others), while others favor ETSs (Keohane, 2009; Ellerman et al., 2016). We compare the two climate policies quantitatively and show that the implementation of ETS substantially reduced emissions, with a three times larger economic significance than the effect of carbon taxes. Moreover, the introduction of carbon taxes helps reduce emissions but does not boost the usage of renewable energy, whereas the implementation of ETSs achieves both goals. The remaining paper will describe the data in Section 2, present the results in Sections 3 and 4, and conclude in Section 5.

2. Data and Summary Statistics

2.1. Carbon Emissions Trading Market (ETS)

We collect the emissions trading market information from the International Carbon Action Partnership (ICAP) fact sheets. For each country, we first identify whether it has implemented a local or national ETS market, and if so, the starting year of the given ETS market. To enhance the accuracy, we conduct due diligence with the formal announcements at each government's website. If a country has several local ETS markets or has both local and national ETS markets, the adoption year of the first ETS market serves as the country-level adoption year. For example, United States started Regional Greenhouse Gas Initiative (RGGI) in 2009 with 9 states and then expanded to 11 states. Another example is that China started eight provincial-level carbon ETS markets in 2013 and launched the national ETS market in 2021—we set China's ETS adoption year as 2013. For countries with ETS markets, we further collect the carbon emission cap at the annual frequency since its ETS implementation.

The operating carbon markets can be classified into two groups: 1) cap on absolute emission levels such as ETSs in EU, Switzerland, New Zealand, Republic of Korea, and the United States' California; and 2) cap on the intensity of emission generation to production, such as China's ETS.

2.2. Emissions and Economic Activities

We collect emissions data at the country-year level from the Bloomberg ESG database for our sample period. It offers two emission measures: the CO2 emission from 2000 to 2020 and the GHG emissions from 2000 to 2018, including CO2, methane (CH4), nitrogen oxide (N2O), and fluorinated gases (F-gases).

We download country-year level economic activities from World Bank and International Monetary Fund (IMF). Specifically, the data for GDP, population, unemployment rate, industrial structure (e.g., value-added from agriculture, industry, manufacturing, and services), and electricity sources are from World Bank. The IMF data for government revenue, expenditure, and gross debt are more comprehensive and thus are downloaded there. Our sample includes the 100 largest countries by GDP as of 2020.

2.3. Carbon Tax

For an alternative carbon pricing instrument, we consider carbon taxes and collect their implementation year at the country level. We hand-collect the country list from World Bank's Carbon Pricing Dashboard, supplement it with information on Wikipedia's "Carbon Tax" page, and conduct Google searches to validate it. Table 1 lists all countries in our sample that has implemented ETS or carbon tax, and corresponding adoption years.

2.4. Summary Statistics

Table 2 shows the summary statistics for the country-year panel data across the 100 countries in our sample. Panel A provides the emission variables from 2000 to 2020. The average country-level CO2 (GHG) emission is approximately 309 (417) metric tons per year with a standard deviation of 1,057 (1,286), indicating a huge variation across countries. China and the U.S. have the largest emissions. The average CO2 (GHG) emissions per million in population are 6.529 (9.652) metric tons. *ETS* is the dummy variable for whether a country has an ETS or not, and

CarbonTax is the dummy variable for whether a country has imposed carbon taxes or not at a given year. Panel B presents the percentage of electricity production from each energy source from 2000 to 2015. Fossil fuels (*Electricity_OilGasCoal*), on average, contribute 59.875% of electricity production across countries over the sample period. Coal (*Electricity_Coal)* alone contributes 17.593% of electricity production. On the other side, clean energy such as nuclear, hydropower, and renewable energy contribute 7.996%, 26.117%, and 3.780% of electricity production, on average, respectively. Some countries, such as Qatar, completely rely on fossil fuels to generate electricity but other countries, such as Demark, use renewable energy extensively for electricity.

3. Empirical Results

3.1. The ETS Impact on Emissions

We rely on the staggered ETS implementations across countries to identify the effect of carbon trading policy shocks on global emissions. Formally, we estimate the following regression:

$$Y_{it} = \alpha + \beta \times ETS_{it} + Controls_{it} + FE + \varepsilon_{it}, \quad (1)$$

where Y_{it} indicates the emission outcome by country *i* in year *t*. We consider both the level of emissions, *LogCO2* and *LogGHG*, and the per capita emissions, *LogCO2_percapita* and *LogGHG_percapita*. ETS_{it} is an indicator equal to one in the year of the ETS implementation by country *i* and the following years, and zero otherwise. Among the 100 countries in our sample, 34 have launched a national or regional ETS, which are treated following the initiation of their ETS markets. For the other 66 countries that have never had an ETS market, ETS_{it} is always zero. We set the sample period from 2000 to 2020 given that the earliest ETS market started in 2005 (EU ETS). In all regressions, we include two pre-trend indicators, *ETS_Pre1* and *ETS_Pre2*, which is equal to one in the one and two years before the country launched the ETS, respectively, and the following years. We also control for countries' economic barometers possibly related to country-level emissions such as GDP, population, unemployment rate, revenue, expenditure, and value-added GDP from various industry sectors. Lastly, we include country and year fixed effects.

Panel A of Table 3 presents the results and shows that ETS implementation substantially reduced GHG and CO2 emissions. We find that the coefficients of *ETS* are negative and statistically significant at the 1% level in all four regressions. For example, Column (1) shows that implementation of ETSs induced an 18.1% (=exp (0.166)-1) reduction in CO2 emission, which is economically large. To gauge the economic effect of this result, we compare the coefficient estimate to the standard deviation of the CO2 coefficient after accounting for country and year fixed effects. This standard deviation of *LogCO2* is 1.62, suggesting that the existence of an ETS explains about 10.2% (=0.166/1.62) of the variation of CO2 emissions after controlling for fluctuations in emissions accounted for by country and year effects. That said, country and year fixed effects explain much more of the total variation in emissions than ETS implementations. Results in Columns (2)– (4) indicate that ETS implementations induced a 12.1% reduction in GHG emissions and an 11.5% (10.1%) reduction in the CO2 (GHG) emissions per capita.

The results in Panel A also indicate that ETS implementation effectively reduces emissions even when controlling for the pre-trend indicators and several time-varying country-level factors. The coefficients of pre-trend dummies are insignificant, which alleviates the concern of reverse causality.

3.2. Dynamics of the ETS Impact on Emissions

One potential concern with any DID design is that the post-treatment effect could be the consequence of a pre-existing trend unrelated to the treatment itself. This is of less concern in the case of a staggered DID design because these potential pre-existing trends would have to occur multiple times and be staggered like the actual treatment effects to explain the results. Nevertheless, we conduct formal parallel trend tests and plot the yearly coefficients on the ETS policy shocks, together with ninety-five percent confidence intervals in Figure 1. The regression specification below is the same as in Equation (1), except that the effect of ETS is allowed to vary by year for each year starting 10 years prior to the ETS adoption and ending 10 years after the adoption:

$$Y_{it} = \alpha + \beta_1 \times ETS_{it}^{-10} + \beta_2 \times ETS_{it}^{-9} + \cdots + \beta_{25} \times ETS_{it}^{+10} + Controls_{it} + FE + \varepsilon_{it}. \qquad (2)$$

Here ETS_{it}^{-j} is a dummy variable that equals one for country *i* in the j^{th} year before its ETS adoption. We exclude the year of ETS adoption, thus estimating the dynamic effect of ETS shocks on the emissions relative to the year of ETS adoption. We again control for the economic variables as well as year and country fixed effects.

Figure 1 illustrates two key points: emission reduction does not precede ETS adoption, and the impact of ETS on emissions materializes quickly. The coefficients of the year-by-year ETS effect are positive or insignificantly different from zero for all years before the ETS adoption. The coefficients fall one year after the adoption, negative and significant at the 5% level, and also show a strong downward trend. Thus, the mechanism connecting ETSs with emission reduction must be fast-acting.

3.3. Mechanism: The ETS Impact on the Sources of Electricity Production

We next explore the potential mechanisms underlying the reduced emission levels following ETS implementations. The largest share of global GHG emissions can be attributed to electricity and heat production. We examine how ETS implementations change the sources of electricity production by employing the same method described in Section 3.1. In particular, we consider five sources contributing to electricity production: coal, fossil fuels (oil, gas, and coal), nuclear, hydropower, and renewable energy.

Panel B of Table 3 presents the results. In Column (1), the coefficient of *ETS* is −4.169 at the 1% significance level, suggesting that the percentage of electricity production from coal sources decreased by 23.70% (=4.169/17.593) following ETS adoption. Similarly, ETS adoption induced a reduction of the electricity production from fossil fuels by 5.45% (=3.265/59.875), as shown in Column (2). In contrast, the coefficients of *ETS* are 1.315 and 2.328 in Columns (4) and (5), both significant at the 1% level, suggesting that after ETS adoption, the percentage of electricity production from hydropower and renewable energies increased by 5.04% (=1.315/26.117) and 61.59% (=2.328/3.780), respectively. These findings clearly highlight that countries use cleaner sources of energy after implementing an ETS, which explains the ETS-induced emission reduction shown in Panel A.

In Panel B of Table 3, we also include the pre-trend dummies, *ETS_Pre1* and *ETS_Pre2*. The coefficients for both pre-trend variables are insignificantly different from zero. We conduct the formal parallel trend test for the percentage of electricity production contributed by renewable energy. Figure 2 shows that the coefficients of the year-by-year ETS effect were negative and insignificant before ETS adoption, but the coefficients increased substantially after adoption. These findings confirm that changes in renewable energy as the source of electricity production do not precede ETS adoption. Combined with the earlier result that ETS adoption leads to reduced emissions, we believe the reduced emissions are related to the substitution of fossil fuels with renewable energy sources.

3.4. The Ongoing Impact of ETS after Adoption

In Sections 3.1–3.3, we examine the impact of ETS adoption on emissions and the usage of renewable energy, however the impact is not limited to initial launch. After ETS implementation, a country often adjusts the cap on emissions to achieve its climate policy target gradually. In our sample, the average annual emission cap is 60.5 million metric tons with a standard deviation of 94.2 million. In this section, we study the impact of ETS cap changes on emissions and the usage of various energy sources to generate electricity. Specifically, we restrict our sample to the countries and years with established ETS markets (i.e., *ETS*=1) and run the regressions as in Sections 3.1 and 3.3, substituting the main explanatory variable, *ETS*, with *LogETSCap*, the natural logarithm of one plus the total emission allowance by a country at a given year.

Panel A of Table 4 presents the results. The coefficients of *LogETSCap* are significantly positive in all regressions for emission outcome variables, suggesting that tightening emission allowances indeed leads to lower real emissions. For example, reducing the emission allowance by half leads to approximately 3.95% (=log (0.5)×0.057) and 2.77% (=log (0.5)×0.040) decreases in CO2 and GHG emissions, respectively. Interestingly, we find that tightening emission allowances in ETS markets also significantly reduces the usage of fossil fuels and increases the usage of renewable energy, nuclear, and hydropower in producing electricity, as shown in Panel B. For example, reducing the emission allowance by half leads to an approximately 9.688% (=log (0.5)×8.369/59.875) decrease in the usage of fossil fuels and a 59.266% (=log (0.5)×3.232/3.780) increase in the usage of renewable energy for electricity production.

These findings robustly show that when governments impose stronger restrictions on carbon emission allowance through ETS markets, countries switch from fossil fuels to renewable energy, leading to substantially lower carbon emissions.

4. Carbon Trading versus Carbon Tax

In this section, we compare the performance of ETSs and carbon taxes, another popular carbon pricing instrument, in reducing emissions. First, we independently study the impact of carbon taxes by repeating the analysis in Sections 3.1 and 3.3, substituting the policy shock from *ETS* with *CarbonTax*. Panel A of Table 5 shows that the implementation of a carbon tax is also associated with reduced emissions in all four emission outcomes, with a smaller impact than ETS. However, such emission reduction also happened before the tax adoption with significant coefficients on the pre-trend variables. Thus, it is difficult to conclude that levying a carbon tax leads to emissions reduction. Furthermore, Panel B of Table 5 shows that carbon taxes have no impact on the energy usage compositions. That is, the percentage of electricity production from each source does not change significantly after levying a carbon tax. Overall, these findings suggest that carbon taxes are not as effective as carbon trading.

Second, we investigate whether the proclaimed causality effect of ETS on emissions is partially due to an earlier established carbon tax policy, focusing on a subsample of countries that imposed a carbon tax before adopting an ETS (Table 6). Including both *ETS* and *CarbonTax* dummies in the regressions, we find that the coefficients of *ETS* remain significantly negative for all emission outcomes, whereas the coefficients of *CarbonTax* are mostly positive and insignificantly different from zero. These findings suggest that even with existing carbon tax policies, the launch of carbon trading markets can still effectively reduce the emission levels.

5. Conclusion

Global warming poses imminent and long-term threats to the survival of all species, and the economic losses could also be massive. Although many countries have made efforts to combat global warming, e.g., by reducing GHG emissions and switching to more sustainable energy, overall temperatures have nevertheless been increasing worldwide. We document the important role of the cap-and-trade system in reducing carbon emissions, and the fundamental mechanisms (i.e., transition to renewable energy) underlying such reductions. This has broad policy implications in all countries worldwide.

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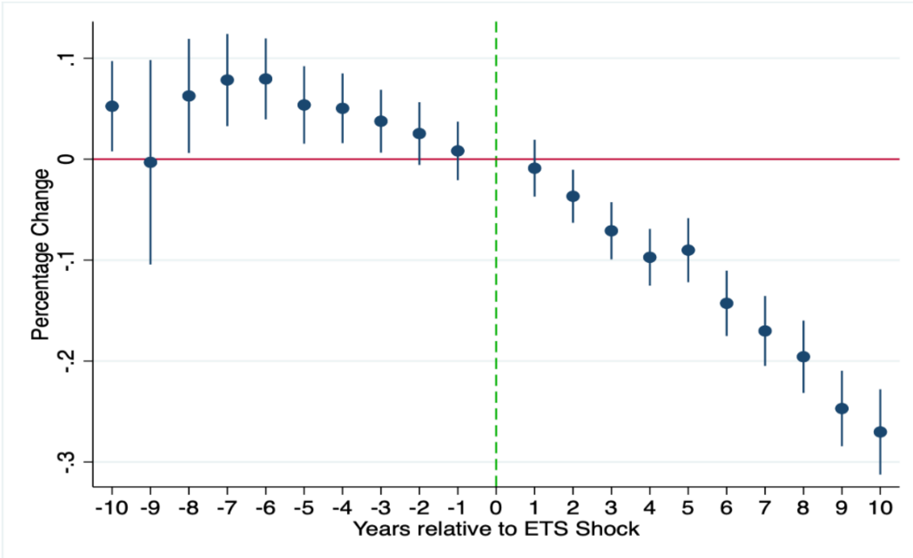
Appendix: Key Variable Definition

Variables	Definition
LogCO2	CO2 emissions (in metric tons of CO2), including emissions from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals and urea), and product use.
GHG	Greenhouse gas emissions (in metric tons of CO2 equivalent), consisting of CO2, CH4, N2O and F-gases emissions.
CO2_percapita	CO2 emissions per million population (in tons of CO2).
GHG_percapita	Greenhouse gas emissions per million population (in tons of CO2 equivalent).
LogCapETS	The natural logarithm of one plus the cap of GHG emissions in a country in a year (in metric tons of CO2).
ETS	Dummy variable for whether a country has a carbon exchange system (ETS) or not in a given year.
CarbonTax	Dummy variable for whether a country has carbon taxes or not in a given year.
Electricity_Coal	Electricity production from coal sources (% of total). Coal sources include both primary and coal-derived fuels.
Electricity_OilGasCoal	Electricity production from oil, gas, and coal sources (% of total). Oil refers to crude oil and petroleum products. Gas refers to natural gas but excludes natural gas liquids. Coal refers to both primary and coal-derived fuels.
Electricity_Nuclear	Electricity production from nuclear sources (% of total). Nuclear power refers to electricity produced by nuclear power plants.
Electricity_Hydroelectric	Electricity production from hydroelectric sources (% of total). Hydropower refers to electricity produced by hydroelectric power plants.
Electricity_Renewable	Electricity production from renewable sources, excluding hydroelectric (% of total). Electricity production from renewable sources, including geothermal, solar, tides, wind, biomass, and biofuels.
LogGDP	The natural logarithm of one plus GDP of the country (in US dollars).
LogPopulation	The natural logarithm of one plus population of the country.
Unemployment	Unemployment rate (in %), the number of unemployment divided by the total labor force, is the share of the labor force that is without work but available for and seeking employment.
LogRevenue	The natural logarithm of one plus general government revenue (in billions of local currency), which consists of taxes, social contributions, grants receivable, and other revenue.
LogExpenditure	The natural logarithm of one plus general government total expenditure (in billions of local currency), which consists of total expense and the net acquisition of nonfinancial assets.
LogDebtGross	The natural logarithm of one plus general government gross debt (in billions of local currency), consists of all liabilities that require payment or payments of interest and/or principal in the future.
LogAgriculture	The natural logarithm of one plus agriculture, forestry, and fishing, value added (in US dollars), which is the net output of agriculture, forestry, and fishing after adding up all outputs and subtracting intermediate inputs.
LogIndustry	The natural logarithm of industry (including construction), value added (in US dollars), which is the net output of the industry.
LogManufacturing	The natural logarithm of one plus manufacturing, value added (in US dollars), which is the net output of manufacturing.
LogServices	The natural logarithm of one plus services, value added (in US dollars), which is the net output of services.

A. GHG Emissions



B. **CO2 Emission**

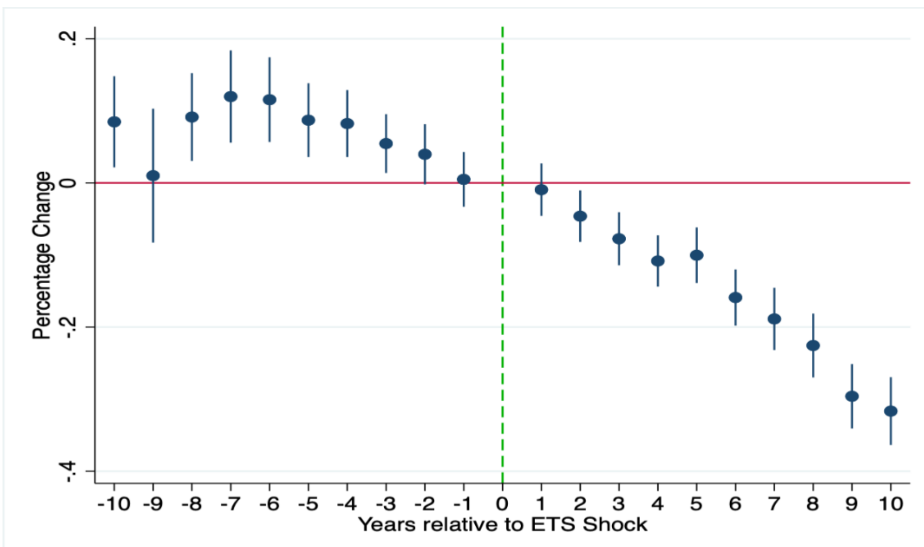


Figure 1: Dynamic Impact of ETSs on GHG and CO2 Emissions. The figure plots the impact of ETS implementations on the natural logarithm of GHG and carbon dioxide emissions. We consider a 20-year window, spanning from 10 years before the ETS policy shock until 10 years after ETS adoption. The solid lines represent 95% confidence intervals. Specifically, we report estimated coefficients from regression equation (2). We exclude the year of ETS adoption (i.e., 0 in the horizontal axis), thus estimating the dynamic effect of ETSs on GHG and CO2 emission relative to the year of ETS inception.

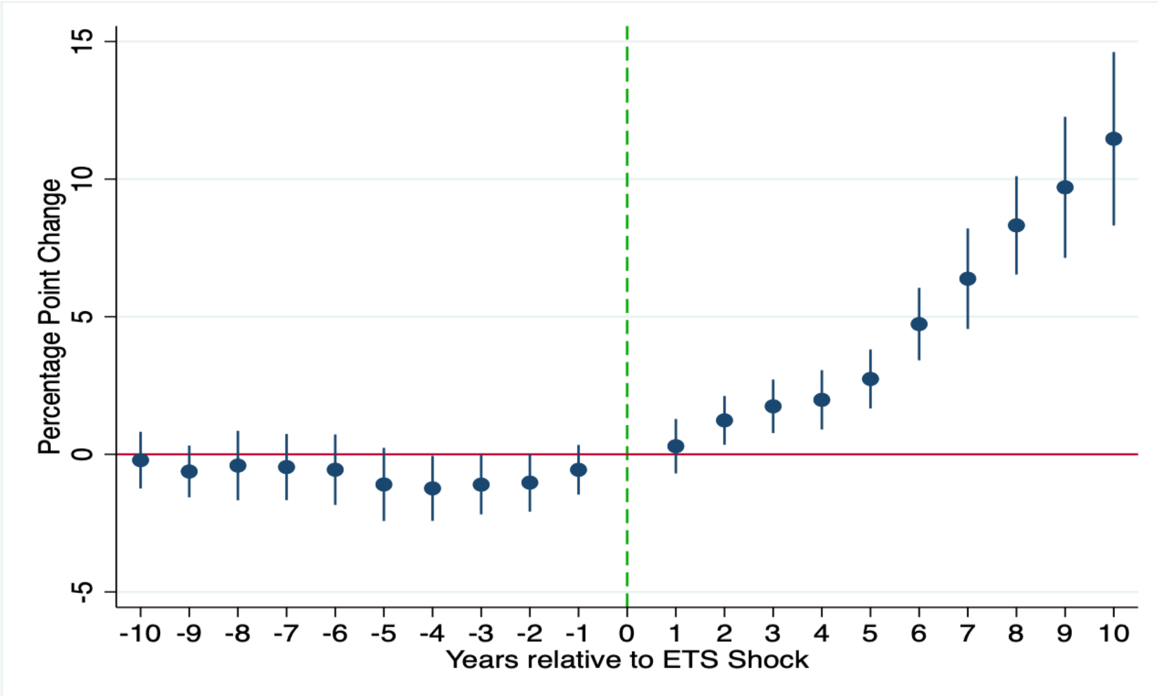


Figure 2: Dynamic Impact of ETSs on Renewable Energy. The figure plots the impact of ETS implementations on the natural logarithm of renewable energy usage. We consider a 20-year window, spanning from 10 years before the ETS shock until 10 years after ETS adoption. The solid lines represent 95% confidence intervals. Specifically, we report estimated coefficients from regression equation (2). We exclude the year of ETS adoption (i.e., 0 in the horizontal axis), thus estimating the dynamic effect of ETS on renewable energy usage relative to the year of ETS inception.

Table 1
The Adoption Year of ETSs and Carbon Taxes

Country	ETS Adoption Year	Tax Initiation Year
Canada	2013	2019
Denmark	2005	1992
Estonia	2005	2000
Finland	2005	1990
France	2005	2014
Germany	2005	2019
Ireland	2005	2010
Japan	2010	2012
Latvia	2005	2004
Norway	2008	1991
Poland	2005	1990
Portugal	2005	2015
Slovenia	2005	1996
Spain	2005	2014
Sweden	2005	1991
Switzerland	2008	2008
United Kingdom	2005	2013
Argentina	N/A	2018
Australia	N/A	2012
Chile	N/A	2017
Colombia	N/A	2017
Mexico	N/A	2014
Nigeria	N/A	2019
Singapore	N/A	2019
South Africa	N/A	2019
Ukraine	N/A	2011
Austria	2005	N/A
Belgium	2005	N/A
Bulgaria	2007	N/A
China	2013	N/A
Croatia	2013	N/A
Czech Republic	2005	N/A
Greece	2005	N/A
Hungary	2005	N/A
Italy	2005	N/A
Korea, Rep.	2015	N/A
Lithuania	2005	N/A
Luxembourg	2005	N/A
Netherlands	2005	N/A
New Zealand	2008	N/A
Romania	2007	N/A
Slovak Republic	2005	N/A
United States	2009	N/A

Note: This table presents information of the ETS launching years for 34 countries and carbon tax initiation years for 26 countries among the top 100 countries in terms of GDP in our sample. 17 countries have implemented both carbon tax and ETS.

Table 2
Summary Statistics

Variables	Observations	Mean	STD	Min	Max
Panel A: Emission Data					
CO2	2,100	309.469	1057.869	1.622	11680.420
GHG	1,900	417.238	1286.403	4.118	13739.790
CO2_percapita	2,100	6.529	6.972	0.035	56.554
GHG_percapita	1,900	9.652	10.779	0.455	107.761
LogCapETS	431	17.058	1.387	11.104	20.214
Panel B: Electricity Source Data					
Electricity_Coal	1,552	17.593	24.144	0.000	96.331
Electricity_OilGasCoal	1,552	59.875	31.888	0.000	100.000
Electricity_Nuclear	1,488	7.996	16.669	0.000	82.239
Electricity_Hydroelectric	1,552	26.117	29.614	0.000	100.000
Electricity_Renewable	1,552	3.780	6.691	0.000	65.444

Note: This table presents the summary statistics of our sample data. The sample is for the country-year panel across 100 countries from 2000 to 2020. Panel A is for the emission data from 2000 to 2020 (GHG emission data end in 2018). Panel B is for the composition of electricity source data from the World Bank from 2000 to 2015. See Appendix for variable definitions.

Table 3
The Impact of ETS Implementations on Emissions and Electricity Power Sources

Panel A	(1) LogCO2	(2) LogGHG	(3) LogCO2_percapita	(4) LogGHG_percapita
ETS	−0.166***	−0.114***	−0.109***	−0.096***
	(0.017)	(0.012)	(0.013)	(0.011)
ETS_Pre1	−0.049**	−0.020	−0.017	−0.014
	(0.020)	(0.014)	(0.015)	(0.013)
ETS_Pre2	−0.019	−0.008	0.001	−0.004
	(0.020)	(0.015)	(0.016)	(0.013)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	1,876	1,717	1,876	1,717
R-squared	0.994	0.997	0.991	0.992

Panel B	(1) Electricity_ Coal	(2) Electricity_ OilGasCoal	(3) Electricity_ Nuclear	(4) Electricity_ Hydroelectric	(5) Electricity_ Renewable
ETS	−4.169***	−3.265***	−0.352	1.315**	2.328***
	(0.595)	(0.942)	(0.674)	(0.635)	(0.420)
ETS_Pre1	−1.044	−0.395	0.336	0.310	−0.437
	(0.645)	(1.310)	(1.145)	(0.787)	(0.478)
ETS_Pre2	0.014	1.084	0.290	−0.537	−0.754
	(0.687)	(1.376)	(1.159)	(0.977)	(0.546)
Controls	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,407	1,407	1,347	1,407	1,407
R-squared	0.975	0.959	0.940	0.971	0.855

Note: This table presents regression results of the impact of the ETS implementations on emissions in Panel A and on the usage of various electricity power sources in Panel B. ETS is the dummy variable indicating whether a country has an ETS or not at a given year. ETS_Pre1 and ETS_Pre2 are dummies that equal one for one or two years before a country implements the ETS and zero otherwise. The sample covers 100 countries from 2000 to 2020 in Panel A and from 2000 to 2015 in Panel B. We control for country-level characteristics including *LogGDP*, *LogPopulation*, *Unemployment*, *LogRevenue*, *LogExpenditure*, *LogDebtGross*, *LogAgriculture*, *LogIndustry*, *LogManufacturing*, *LogServices* in all columns. Robust standard errors are reported in parentheses. Superscript ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 4

The Impact of Carbon Emission Cap on Emissions and Electricity Power Sources

Panel A	(1) LogCO2	(2) LogGHG	(3) LogCO2_percapita	(4) LogGHG_percapita
LogETSCap	0.057***	0.040***	0.711***	0.038***
	(0.010)	(0.007)	(0.108)	(0.006)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	403	353	403	353
R-squared	0.999	0.999	0.983	0.992

Panel B:	(1) Electricity_ Coal	(2) Electricity_ OilGasCoal	(3) Electricity_ Nuclear	(4) Electricity_ Hydroelectric	(5) Electricity_ Renewable
LogETSCap	2.020**	8.369***	-3.655**	-1.151*	-3.232***
	(0.831)	(1.407)	(1.657)	(0.653)	(0.799)
Controls	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	258	258	254	258	258
R-squared	0.982	0.964	0.930	0.988	0.921

Note: This table presents regression results of the impact of the emission cap imposed by ETSs on emissions in Panel A and on the usage of various electricity power sources in Panel B. The sample is from 2000 to 2020 but only include the time period that a country has an ETS. LogETSCap is the natural logarithm of one plus the total emission level allowed for a country under ETS. We control for *LogGDP, LogPopulation, Unemployment, LogRevenue, LogExpenditure, LogDebtGross, LogAgriculture, LogIndustry, LogManufacturing, LogServices* in all columns. Robust standard errors are reported in parentheses. Superscript ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 5
The Impact of Carbon Tax Implementations on Emissions and Electricity Power Source

Panel A	(1) LogCO2	(2) LogGHG	(3) LogCO2_percapita	(4) LogGHG_percapita
CarbonTax	−0.136***	−0.094***	−0.087***	−0.076***
	(0.017)	(0.016)	(0.014)	(0.014)
CarbonTax_Pre1	−0.070***	−0.067***	−0.044**	−0.054***
	(0.022)	(0.019)	(0.017)	(0.016)
CarbonTax_Pre2	−0.058***	−0.057***	−0.033**	−0.045***
	(0.019)	(0.017)	(0.014)	(0.015)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,251	2,092	2,251	2,092
R-squared	0.992	0.995	0.988	0.989

Panel B	(1) Electricity_ Coal	(2) Electricity_ OilGasCoal	(3) Electricity_ Nuclear	(4) Electricity_ Hydroelectric	(5) Electricity_ Renewable
CarbonTax	0.201	0.797	−1.302	0.559	0.007
	(1.175)	(1.471)	(1.062)	(0.704)	(0.806)
CarbonTax_Pre1	−0.763	−0.989	−0.986	0.963	0.831
	(1.427)	(1.942)	(1.012)	(0.822)	(1.232)
CarbonTax_Pre2	0.677	0.104	0.497	−1.053	0.278
	(1.541)	(1.709)	(0.759)	(1.256)	(1.071)
Controls	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,779	1,719	1,779	1,779
R-squared	0.958	0.954	0.948	0.966	0.796

Note: This table presents regression results of the impact of carbon tax implementations on emissions in Panel A and on the usage of various electricity power sources in Panel B. CarbonTax is the dummy variable indicating whether a country has carbon taxes or not at a given year. CarbonTax_Pre1 and CarbonTax_Pre2 are dummies that equal one for one or two years before the country first imposed carbon taxes and zero otherwise. The sample is from 1985 to 2015. We control for *LogGDP*, *LogPopulation*, *Unemployment*, *LogRevenue*, *LogExpenditure*, *LogDebtGross*, *LogAgriculture*, *LogIndustry*, *LogManufacturing*, *LogServices* in all columns. Robust standard errors are reported in parentheses. Superscript ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 6
Carbon Tax and ETS on Emissions (subsample with Carbon Tax before ETS)

	(1)	(2)	(3)	(4)
	LogCO2	LogGHG	LogCO2_percapita	LogGHG_percapita
CarbonTax	0.030	0.013	0.028*	0.013
	(0.019)	(0.017)	(0.016)	(0.015)
ETS	−0.050*	−0.037*	−0.049**	−0.036*
	(0.027)	(0.021)	(0.022)	(0.019)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	488	455	488	455
R-squared	0.992	0.996	0.981	0.982

Note: This table presents the results of the impact of carbon tax and ETS implementations on emissions. The sample is from 1985 to 2020 for countries with a carbon tax imposed before an ETS. ETS and CarbonTax are dummy variable indicating whether a country has an ETS or carbon tax at a given year. We control for *LogGDP*, *LogPopulation*, *Unemployment*, *LogRevenue*, *LogExpenditure*, *LogDebtGross*, *LogAgriculture*, *LogIndustry*, *LogManufacturing*, *LogServices* in all columns. Robust standard errors are reported in parentheses. Superscript ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.