Carbon Taxes, Globalization, and the Geography of Emissions*

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Abstract

This paper studies the impact of national carbon taxes on emissions. To do so, we construct a cross-country panel dataset, matching measures of emissions of carbon dioxide with information on the introduction of carbon taxes and their implied price. Importantly, we consider both measures of *territorial* emissions — emissions emitted within a country's borders — and *consumption* emissions — emissions emitted anywhere in the world to satisfy domestic demand. Using panel local projection methods, we find that carbon taxes reduce territorial emissions over time, but have no significant effect on consumption emissions. Our estimates are robust to propensity-score weighting adjustments and are driven by countries which are more open to trade. Carbon taxes also lead to a modest increase in imports, suggesting that international trade may act as a conduit for reallocating the production of emissions away from locations where carbon is taxed. Together, our findings highlight the limitations of national carbon taxes in isolation and the importance of international cooperation in reducing global emissions.

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1 Introduction

Emissions of carbon dioxide (CO_2) are a key driver of climate change and a major threat to lives and livelihoods. While carbon emitted anywhere in the world has adverse environmental consequences for the planet as a whole, emissions of CO_2 vary widely across countries. Figure 1 shows that carbon emissions are considerably higher in some countries than others, even when taking in to account differences in population.[1] This is evident even within continents, including Europe (see Figure 2).

In response to the threat of climate change, governments around the world have introduced policies to reduce emissions of carbon, or at least slow their growth. How successful these policies have been remains an open question (Copeland, Shapiro, et al., 2022), especially as global carbon emissions continue to rise (see Figure 3). Amongst the menu of options policy makers face, carbon taxes have arguably garnered the most attention and are generally seen as an effective policy tool (Hassler et al., 2016). Skeptics, however, suggest that while carbon taxes may reduce emissions within their jurisdiction, the source of emissions may simply shift to locations in which they are not taxed, or taxed at a lower rate — the process of "carbon leakage" (Copeland, Shapiro, et al., 2022).

In this paper we estimate the effects of national carbon taxes on emissions across countries and time. Importantly, we consider both measures of domestic — or, *territorial* emissions — as well as measures which also account for the emissions emitted abroad to satisfy domestic demand — or, *consumption* emissions. The difference in effects on these two types of emissions gives us an indication of whether carbon taxation spurs international carbon leakage. To further investigate this channel, we study how our estimates vary with openness to trade, as well as the impact of carbon taxes on imports.

Our estimates show that carbon taxation has a negative, cumulative impact on territorial emissions over time, but no impact on consumption emissions. We further find that our results are largely driven by countries that are more open to trade, and that carbon taxation leads to an increase in imports. Together, these findings suggest that countries with carbon taxes

[1] Emissions patterns also vary widely when normalising aggregate emissions by GDP. While there are some differences, total emissions, emissions per capita, and emissions per unit of GDP are highly correlated across countries (see, for instance, de Silva and Tenreyro, 2021). In our analyses we control for both income and population to account for these differences.

may offset the reduction in territorial emissions by outsourcing the production of emissions, shifting their source without reducing demand for them, and contributing to carbon leakage.

Our empirical analyses is motivated by a number of stylized facts that we document in this paper. First, we show that trends in emissions vary widely across countries. In particular, emissions have been flat or falling in many advanced economies which have more stringent environmental policies, including more ambitious emissions reductions targets. In contrast, emissions have been rising in many emerging market economies, particularly in China and India. Next, we show that net emissions — or the difference between consumption and territorial emissions — also vary widely across countries. In particular, net emissions in economies with more ambitious emissions reduction targets are positive and have been growing, suggesting that emissions due to domestic demand are higher than emissions emitted within their boarders. In contrast, net emissions for many emerging market economies are negative and declining, suggesting that a large share of the emissions produced domestically are to satisfy foreign demand. A potential explanation for these patterns is that environmental policies, including carbon taxes, may be driving the sources of emissions from advanced to emerging market economies — the so-called "pollution haven" hypothesis.

Motivated by these stylized facts, we then turn to an empirical analysis of the impact of carbon taxes on emissions. We first build a panel dataset matching measures of territorial and consumption emissions with data on the timing and implied price of carbon taxes for a large sample of countries. In particular, our sample includes many emerging market and developing economies traditionally ignored in studies of emissions, and crucial for investigating the phenomenon of carbon leakage. We then estimate the dynamic effects of carbon taxation on emissions using panel local projection methods following Jordà (2005) and Jordà and A. M. Taylor (2016) and controlling for all time and country-specific factors that impact emissions, as well as cross country differences in income and population.

Our estimates show that national carbon taxes have a negative, cumulative impact on territorial emissions of roughly 9 % within 5 years of implementation. This corresponds to a roughly 0.1 % reduction in emissions per implied USD price of carbon. Our estimates of the impact of carbon taxes on consumption emissions, however, are much smaller in magnitude and are not significant at any conventional level of statistical significance, both for the implementation and implied price of taxation.

Carbon taxes are of course not randomly allocated across countries, but rather a policy tool implemented by authorities. As such, the decision to impose a tax on carbon may be itself a function of a country's emissions. To address this potential source of endogeneity in our estimates, we apply propensity score matching to our panel local projections in the form of inverse propensity score weighting (IPW) as in de Silva and Tenreyro (2021) and Jordà and A. M. Taylor (2016). IPW works, as all propensity score matching methods, by giving higher weights to observations based on their likelihood of being treated (introducing a carbon tax) inferred via select covariates. The aim of IPW is to give a higher weight to treatment and control observations which are more comparable in terms of observable characteristics. The pattern of results from our IPW estimations largely confirm the findings from our baseline model. The magnitude of our IPW estimated effects of carbon taxes on territorial emissions are around two-thirds as large as our baseline estimates — a roughly 6% reduction within 5 years. Our IPW estimates also find no evidence of a significant effect of carbon taxes on consumption emissions.

Our findings of a significant, negative effect of carbon taxes on territorial emissions, but no effect on consumption emissions suggest that carbon taxation leads to some degree of carbon leakage. To investigate this potential mechanism further, we look to two additional analyses. First, we study how our results vary with openness to trade as countries which are more open to trade may be better able to shift emissions outside of their borders. We proceed by splitting our sample into countries with above median openness to trade (high openness to trade) and countries with below median openness to trade (low openness to trade) in each year. We then estimate our baseline model augmented with interaction terms to uncover any heterogeneous effects with trade openness. Our results suggest that there are significant differences. We find that countries with low openness to trade see a significant reduction in both territorial and consumption emissions following carbon tax implementation. In the aggregate, the effect on consumption emissions is masked by countries with high openness to trade which see no impact of carbon taxation. Second, we study how the implementation of a carbon tax affects total imports, as carbon leakage joined by a zero effect on consumption emissions should be reflected by an increase in imports. Though noisy, we find some evidence in support of this mechanism. Our estimates suggest that imports increase by 0.1% per implied US dollar price within two years after the introduction of a carbon tax.

This paper contributes to the existing literature in a number of ways. First, we add to the literature studying the effects of carbon taxes on the environment. As emissions are a harmful externality of production, Pigouvian taxes following (Pigou, 1920) are typically seen as economists' preferred policy tool for reducing emissions (Baumol, 1972; Baumol and Oates, 1988; Hassler et al., 2016; Nordhaus, 1977). Notwithstanding concerns over their optimal price (Baumol and Oates, 1971), empirical evidence of the efficacy of carbon taxes is limited.[2] Studies, including Andersson (2019), de Silva and Tenreyro (2021), Känzig (2022), and Metcalf (2019), generally find that carbon pricing from taxes and cap-and-trade systems has a negative impact on emissions. Common to all of these studies, however, is a focus on territorial emissions and a disregard for the potential effects of carbon leakage. Further, most existent literature largely focuses on a limited number of regions (Green, 2021; Köppl and Schratzenstaller, 2022). Kohlscheen et al. (2021) is one exception, looking at the effects of carbon taxes on territorial emissions. This paper fills these gaps in the literature, estimating the impact of carbon taxation on measures of both territorial and consumption emissions. We do so for a large panel of countries, including many emerging market economies, typically ignored in the literature.

This paper also contributes to a literature linking trade to the environment, summarized in a recent review by Copeland, Shapiro, et al. (2022). Copeland and M. S. Taylor (1994) and G. Grossman and Krueger (1993) provide the canonical models of trade and emissions, highlighting a number of channels through which international trade can affect the environment. Within this literature, the phenomenon of carbon leakage is well-defined. Simple pollution haven models, such as Copeland and M. S. Taylor (1995) and Hémous (2016), show that differences in the stringency of environmental policies can induce trade, with emissions intensive production occurring in the country with more lenient policies. Empirical evidence of carbon leakage, however, remains limited. Aichele and Felbermayr (2012) and Aichele and Felbermayr (2015) find that the imports of carbon emissions in countries that signed the Kyoto protocol rose following ratification.[3] Aldy and Pizer (2015) estimate the elasticity of

[2] See Green (2021) and Köppl and Schratzenstaller (2022) for recent reviews.

[3] Branger and Quirion (2014), however, argue that the increase in carbon-intensive imports is due to a large increase in imports from China, largely driven by other factors, including economic growth and decreasing trade costs.

US net imports in fuel-intensive industries to changes in US fuel prices. They then simulate the effects of a US carbon tax using their estimates, and find that carbon leakage would be minimal. To the best of our knowledge, ours is the first paper to provide empirical evidence of carbon leakage from carbon taxes in a cross-country setting.

Our findings have a number of important policy implications. First, for environmental policy, our paper highlights the limitations of domestic policies and the need for international cooperation and coordination to mitigate global emissions (Ferrari and Pagliari, 2021). National carbon taxes will only have a meaningful impact if the production of emissions is unable to be costlessly reallocated across borders. Climate clubs, carbon border adjustments, or a global price on carbon may help to stem carbon leakage by eliminating cross-country differences in the marginal cost of emitting. Second, our results also have implications for a broader set of economic policies more generally. For instance, our findings that

The rest of this paper is structured as follows. Section 2 describes the data and the sample of countries considered. Section 3 presents a number of stylized facts of emissions which motivate our empirical analysis. Section 4 details the empirical model and section 5 presents our results. Section 6 concludes.

2 Data

We construct an annual panel dataset at the country level spanning the years 1991-2018. The dataset combines data on greenhouse gas emissions, carbon taxation, and trade with a broad set of country characteristics and macroeconomic variables. The sample includes 54 countries which together accounted for roughly 91% of global CO_2 emissions in 2018. Importantly, our dataset includes a relatively large number (24) of non-OECD countries, in contrast to the bulk of the literature which largely focuses on advanced economies. A detailed overview of the data and their sources is provided in Table A1 in Appendix A. The countries included in the sample are listed in Table A2.

In our empirical analyses, we focus on emissions data from the Global Carbon Project (GCP). The GCP publishes estimates of annual emissions of CO_2 from the burning of fossil fuels. Estimates of emissions are largely complied based off of data on energy use from the United Nations. A detailed account of the data and the underlying methodologies is given in Andrew and Peters (2021) and Friedlingstein et al. (2021).[4] Emissions data from the GCP offers a key advantage compared with data from other sources. Namely, it contains estimates of *territorial* emissions — emissions emitted within a country's borders — as well as *consumption* emissions — emissions emitted outside of a country's borders that can be attributed to demand in the domestic economy. In practice, consumption emissions for country i are calculated as territorial emissions in i less emissions emitted due to the production of exports in i plus the emissions emitted outside of i emitted to produce i's imports. A detailed overview of the method used to derive estimates of consumption emissions is presented in Peters et al. (2012).

Finally, we collect data on carbon taxes following Laeven and Popov, 2021 and Konradt and Weder di Mauro, 2022 from the World Bank's Carbon Pricing Dashboard.[5] This data contain information on which countries have implemented carbon taxes and the year in which they did so. In addition, the data contain estimates of the implied USD price per ton of carbon for each country and each year. On the basis of this data, we construct two policy variables. The first is a dummy variable equal to one if a country has a carbon tax in a certain year, and zero otherwise. The second is a continuous variable equal to the implied price per ton of carbon in each country in each year in 2018 USD dollars.

Table 1 provides basic descriptive statistics of our sample in 2018. The table displays the sample mean of a number of key variables of interest for all countries in the sample (column 1), countries which had implemented a carbon tax prior to 2018 (column 2), and countries which did not implement a carbon tax in our data (column 3). Column 4 displays the p-value from a two-sided t-test of equality of means between columns 2 and 3. The table shows that countries which implement a carbon tax tend to be somewhat smaller in population, higher income, more likely to be an advanced economy, and have lower emissions in both absolute and per capita terms. Only when it comes to GDP per capita can we reject the null hypothesis of equal means at the 10% level, aligning with the findings in de Silva and Tenreyro, 2021. In addition to controlling for country and time level fixed effects in our empirical approach, we also control for differences in population and GDP per capita to account for these differences.

[4]See also https://www.globalcarbonproject.org/

[5]See https://carbonpricingdashboard.worldbank.org/

3 Stylized Facts of Emissions Patterns

In this section we present a number of stylized facts describing patterns of CO_2 emissions across countries. The facts presented here motivate the empirical analysis which follows in Sections 4 and 5.

Our first set of stylized facts document developments in emissions over time. Figure 4 plots trends in territorial emissions of CO_2 between 1990-2018 for select countries from our sample. Panel 4(a) plots trends for a number of countries listed in Annex B of the Kyoto Protocol.[6] The trends show that territorial emissions in most Annex B countries have remained relatively flat or have fallen over the last three decades. Panel 4(b) plots trends for a number of major emitters not listed in Annex B of the Kyoto Protocol. The trends show that territorial emissions have increased in many non-Annex B countries, in particular in China and India. Together, the data show that trends in emissions vary widely across countries and seem to be related to the binding emissions reductions targets set by countries in the Kyoto agreement.

In terms of the total amount of emissions demanded by each country, the trends plotted in Figure 4 only tell part of the story. If we take in to account the total emissions emitted due to demand in a particular country (or, *consumption* emissions), emissions totals for some countries increase, while for others they decrease. Figure 5 plots trends in net emissions — or the difference in emissions between consumption and territorial emissions. A value above zero indicates that emissions produced to satify domestic demand were higher than those produced within the country, indicating that that country was responsible for emissions produced outside of its boarders. Countries with negative net emissions are next exporters of emissions.

The trends in Panels 5(a) and 5(b) show that net emissions are positive in many Annex B countries, while they are negative in many non-Annex B countries. Further, the data show that net emissions in some annex B countries have been rising while they have been falling in some non-Annex B countries, in particular China and India. Together, these figures suggest that the source of global CO_2 emissions has shifted over the past three decades from

[6] The countries listed in Annex B of the Kyoto protocol pledged to meet binding emissions reductions targets over a number of commitment periods.

many advanced economies with stricter environmental protection policies, towards developing economies with more lenient policies.

4 Model

To estimate the dynamic effects of carbon pricing on emissions of CO_2, we consider the following model following the local projections method in Jordà, 2005, adapted for panel data as in Jordà and A. M. Taylor, 2016

$$\log(CO2_{i,t+h}) - \log(CO2_{i,t}) = \alpha_i^h + \delta_t^h + \varphi^h \Delta \log(CO2_{i,t}) + \beta^h \tau_{i,t} + X'_{i,t}\gamma^h + \epsilon_{it}^h \qquad (1)$$

We estimate (1) over horizons $h = 1 \ldots H$ via OLS. $\log(CO2_{i,t+h})$ is the log of carbon dioxide emissions for country i in year $t + h$. The cumulative changes in log emissions on the left hand are taken from the year of implementation as we assume that impacts will first be felt starting in the following year as taxes are typically liable with a delay. α_i^h are country fixed effects and δ_t^h are time fixed effects. $\tau_{i,t}$ is our main policy variable of interest capturing the carbon taxation. $X_{i,t}$ is a vector of time-varying control variables including log GDP per capita, log GDP per capita squared, and population. We include the square of log real GDP per capita to allow for nonlinear effects of income on emissions — the so-called Environmental Kuznets curve.[7] ϵ_{it} is the error term clustered at the country level.

We estimate (1) for both territorial and consumption emissions, and consider two different policy variables. The first is a dummy variable equal to one if country i had a tax on carbon in year t and zero otherwise. The second is a continuous variable equal to the price per ton of carbon in 2018 US dollars implied by the carbon tax. This variable takes the value of zero for countries that did not have a tax on carbon. β^h is our main parameter of interest capturing the effect of carbon pricing on emissions at horizon h. Estimates of β^h represent the cumulative percent change in emissions given a one unit increased in the policy variable relative to the year of implementation.

[7]Evidence on the existence of the Environmental Kuznets curve is mixed. Xepapadeas (2005) provides a review. Most empirical studies do tend to find evidence of a positive, but decreasing effect of income on emissions (Frankel and Rose, 2005; G. M. Grossman and Krueger, 1995; Stern, 2017).

5 Results

5.1 Dynamic Effects of Carbon Pricing on Emissions

Figure 6 plots the impulse response functions from equation (1) capturing the dynamic effect of carbon tax implementation on territorial (6(a)) and consumption emissions (6(b)). Tables of the underlying estimates are available in Appendix B. The estimates in Panel 6(a) show that carbon taxation has a negative impact on territorial emissions that increases over time and is significant at the 10% level. The estimated cumulative effect stabilizes around 5 years after policy implementation and corresponds to a 9% reduction in territorial emissions relative to the year of introduction. This estimate is somewhat smaller, but comparable to that estimated by de Silva and Tenreyro (2021).

The estimates plotted in Panel 6(b) depict the impulse response function of carbon taxation on consumption emissions. The figure shows that, while the estimated impact is negative, it is smaller in magnitude than the impact on territorial emissions and not significant at the 10% level. As the horizon increases, the estimated impact becomes somewhat more negative, but does not attain statistical significance at any conventional level. Comparing the results across Panels 6(a) and 6(b) suggests that the negative effect of carbon taxes on emissions disappears once we allocate emissions to the country in which demand for them occurs.

Figure 7 plots impulse response functions of territorial and consumption emissions to the implied price per ton of carbon from carbon taxation in 2018 US dollars. The estimates in Panel 7(a) show that territorial emissions are negatively and significantly impacted by the price of carbon. The estimated impact stabilizes around 5 years after the implementation of carbon taxation and corresponds to a 0.1% reduction in emissions per dollar of carbon pricing relative to emissions in the year of introduction. The estimates plotted in Panel 7(b) depict the impact on consumption emissions. As with the results for the carbon taxation dummy, the estimates show that the impact of the price for carbon on emissions is lower when we allocate emissions to the country in which demand for them occurs. The estimate impact on consumption emissions per dollar price of carbon is lower than that for territorial emissions and largely statistically insignificant at most horizons.

Together, these results suggest that while carbon taxation has a negative effect on the emissions emitted within a countries borders — and subject to taxation — the emissions emitted to satisfy domestic demand are seemingly unaffected. These findings suggest that the producers of emissions may be able to shift emissions across borders, avoiding taxation.

5.2 Addressing Potential Endogeneity using Inverse Propensity Weighting

The implementation of a carbon taxes is of course a decision made by authorities. As such, there may be reason to believe that the policy variable in (1) is endogenous and estimates of β^h do not have a causal interpretation. This may be the case if carbon emissions have themselves an effect on the implementation of carbon taxes.

To address this concern, we apply the IPW method to our local projections approach following Jordà and A. M. Taylor, 2016. Specifically, we estimate the following probit model for the countries in our sample

$$\tau_{i,t} = \rho \Delta \log(CO2_{i,t}) + X'_{i,t}\theta + \nu_{it} \tag{2}$$

and use the estimated parameters to calculate predicted values — or propensity scores for the policy variable, $\hat{\tau}_{i,t}$. We then use construct inverse propensity score weights as follows

$$IPW_i = \left(\frac{\tau_{i,t}}{\hat{\tau}_{i,t}}\right) + \left(\frac{1-\tau_{i,t}}{1-\hat{\tau}_{i,t}}\right) \tag{3}$$

Causal identification of the average treatment effect using propensity score matching methods requires the assumption that subjects have a positive probability of being either in the treatment or control groups (the "positivity" assumption). To evaluate this assumption in our setting, we plot the distribution of calculated propensity scores for countries in our sample that implement a carbon tax (the treated) and those that do not (the controls) in Figure 8. As expected, the distribution of propensity scores for the treated lies to the right of the distribution for the control countries. The distributions, however, exhibit significant overlap suggesting that the positivity assumption is reasonably satisfied.

Figure 9 plots the IPW impulse response functions of carbon tax implementation on emissions from equation (1). Tables of the underlying estimates are available in Appendix B. The IPW estimates in Panel 9(a) show that carbon taxation is still estimated to have a negative impact on territorial emissions. The estimated impact increases in magnitude over time and is significant at the 10% level. The estimated cumulative effect stabilizes around 5 years after policy implementation and corresponds to a 6 % reduction in emissions — somewhat smaller in magnitude than the non-weighted estimates presented in Section 5.1. As without weighting, Panel 9(b) shows that the estimated impact on consumption emissions is smaller in magnitude and not significantly different from zero at conventional levels of statistical significance. Together, these results confirm the finding that the negative impact of carbon taxation on emissions seems to disappear once emissions are allocated to the country in which demand for them occurs.

5.3 Dependence on Trade Openness

One factor which may drive the results shown in Sections 5.1 and 5.2 is openness to trade. Countries that are more open to trade may be better able to shift emissions outside of their borders while leaving consumption emissions unaffected. That is, countries that are more open to trade may see an effect of carbon taxation on consumption emissions that is smaller in magnitude and closer to zero than the effect for countries that are less open to trade.

To investigate this possible heterogeneity in our results, we augment our model in (1) with interaction terms as follows

$$\begin{aligned}
&\log(CO2_{i,t+h}) - \log(CO2_{i,t}) = \\
&\quad \alpha_i^h + \delta_t^h + \varphi^h \Delta \log(CO2_{i,t}) + \mu^h TO_{i,t} + \beta^h \tau_{i,t} + \lambda^h (TO_{i,t} \times \tau_{i,t}) + X'_{i,t}\gamma^h + \epsilon_{it}^h \qquad (4)
\end{aligned}$$

where $TO_{i,t}$ is a dummy variable equal to one if country i had a level of trade openness (the sum of imports and exports divided by GDP) greater than the sample median in year t, and zero otherwise. We label countries with above median openness to trade as “high” openness to trade countries, and countries with openness to trade at or below the median as “low” openness to trade countries. λ^h is our parameter of interest which captures the differential effect of carbon taxation on emissions due to trade openness.

Figure 10 plots the main results of our estimates of equation (4) where the policy variable is a dummy equal to one if a country has a carbon tax and zero otherwise. The grey area in each of the panels represents the 90% confidence intervals surrounding estimates of β^h, while the solid lines represent estimates of λ^h surrounded by 90% confidence intervals represented by the dashed lines.

Panel 10(a) plots estimates of the effects on territorial emissions. The results suggest that the effect of carbon taxation on territorial emissions is somewhat less for countries that are more open to trade, yet this difference is not significant at the 10% level. Panel 10(b) plots estimated effects on consumption emissions. The results show that the impact of carbon taxation on consumption emissions does differ with openness to trade. By the fifth year after implementation, carbon taxes are estimated to reduce consumption emissions for countries with low openness to trade, illustrated by the grey area falling below zero. Estimates of the interaction effect shown by the solid line suggest that countries with high openness to trade see a positive relative effect of carbon taxation on consumption emissions. Together, these estimates show that the zero effect of carbon taxation on consumption emissions shown in Sections 5.1 and 5.2 is driven by countries that are more open to trade. This suggests that international trade may act as a conduit for the transfer of emissions across borders following the implementation of carbon taxes, reducing territorial emissions but having no effect on the demand for emissions.

5.4 Dynamic Effects of Carbon Pricing on Imports

The results shown in the previous sections suggest that emitters of carbon may be able to shift emissions across boarders to evade carbon taxation. In this case, we would expect countries with carbon taxes to see an increase in imports following carbon tax implementation (Broner et al., 2012; Ederington and Minier, 2003). To investigate this channel further, we estimate (1) replacing the measures of emissions on the left hand side with total imports.

Figure 11 plots estimates of the dynamic effects of carbon taxation on log total imports. The estimates plotted in Panel 11(a) show the estimated effects for the carbon dummy policy variable. The results show that the countries which implement a carbon tax see a small increase in imports, but this effect is imprecisely estimated and insignificant at conventional levels of statistical significance. Panel 11(b) shows the estimated dynamic effects for the carbon price policy variable. The results paint a similar picture to those for the carbon tax dummy, yet are somewhat more precisely estimated. That is, the price of carbon is associated with an increase in imports. By year 2 following implementation of a carbon tax, imports rise by roughly 0.1% per US dollar price of carbon.

6 Conclusion

The threat of climate change has led to the introduction of a number of national and regional carbon taxes in an effort to reduce emissions of CO_2. Yet the efficacy of carbon taxes remains unclear, particularly when the sources of emissions can be shifted across borders to locations where they are not subject to taxation. This paper estimates the impact of national carbon taxes on emissions. Importantly, we estimate the impact on emissions measures which take into account foreign emissions emitted to satisfy domestic demand. We find that, over time, carbon taxes reduce emissions emitted within a country's borders but have no significant effect on total emissions attributed to domestic demand. These results are driven by countries that are more open to trade. We also find that carbon taxation leads to a modest increase in imports, suggesting that international trade may act as a conduit for reallocating the production of emissions away from carbon taxation. Our results suggest that carbon taxes will only have a meaningful impact on global emissions if emissions cannot be easily shifted across borders, and highlight the need for international cooperation in fighting climate change. Carbon border adjustments, or a global tax on carbon, could help to increase the marginal cost of emitting — regardless of location — reducing global emissions.

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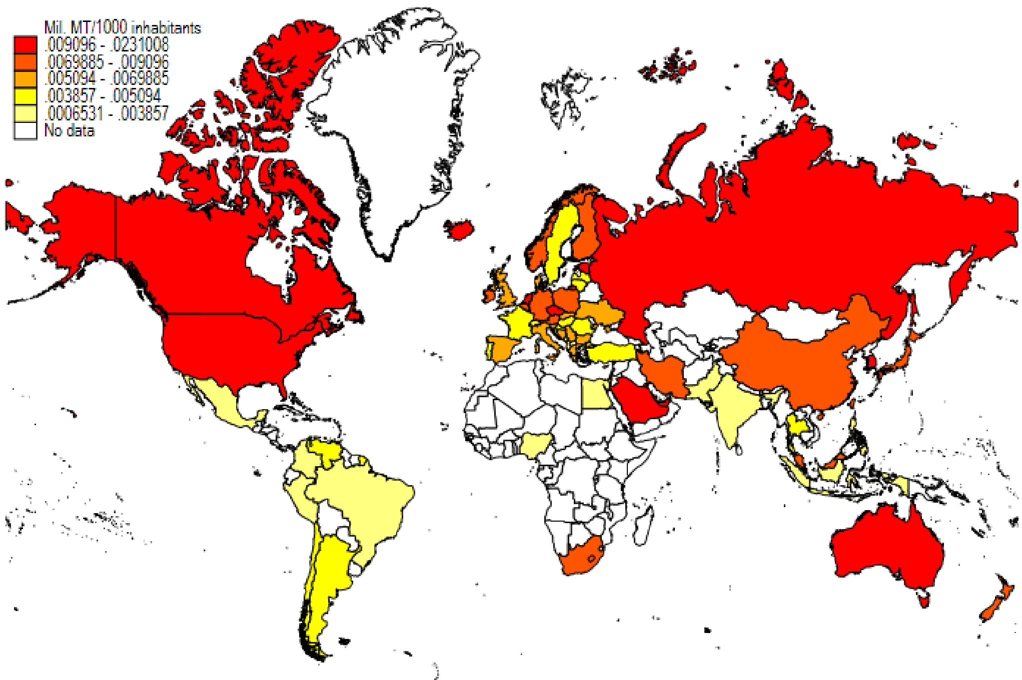
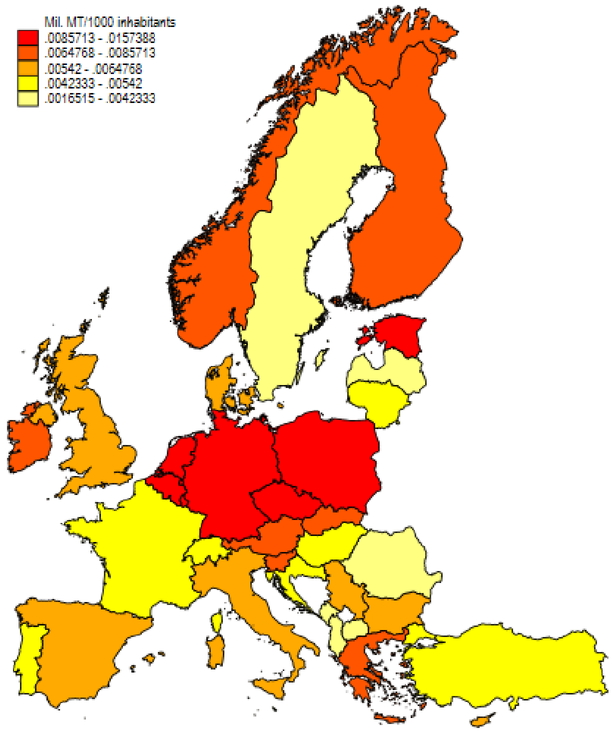
Figure 1: Carbon Dioxide (CO_2) Emissions per capita, 2018



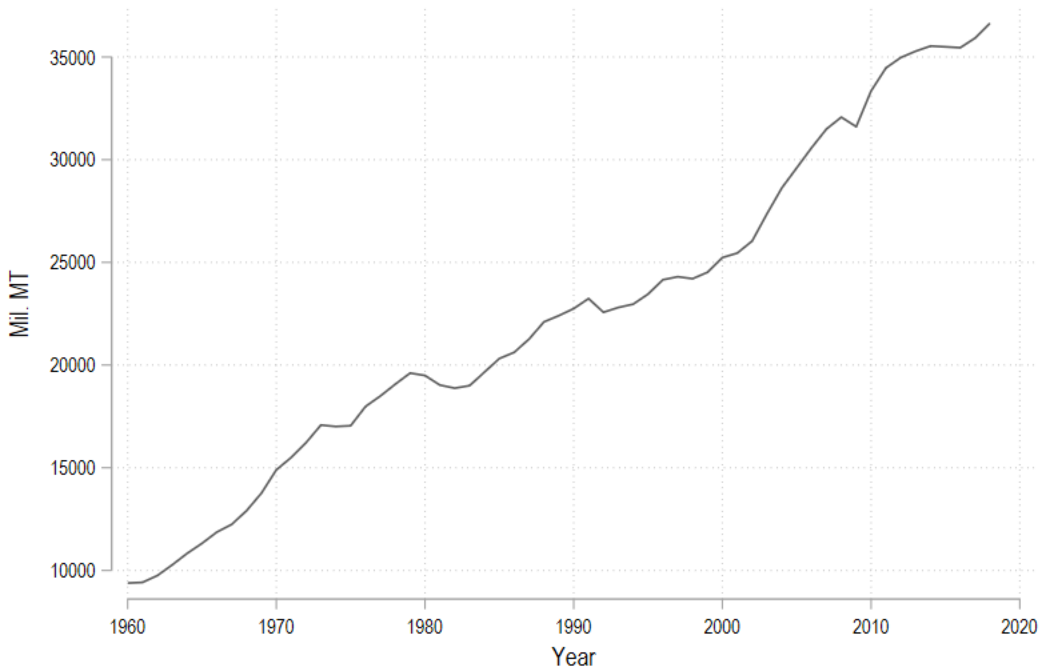
Notes: This figure depicts total territorial emissions of carbon dioxide per capita. Countries with missing data are coloured white. Data on emissions are sourced from the Global Carbon Project. Data on population are sourced from the World Bank.

Figure 2: Carbon Dioxide (CO_2) Emissions per capita



Notes: This figure depicts total territorial emissions of carbon dioxide per capita. Countries with missing data are coloured white. Data on emissions are sourced from the Global Carbon Project. Data on population are sourced from the World Bank.

Figure 3: Global Carbon Dioxide (CO_2) Emissions, 1960-2018

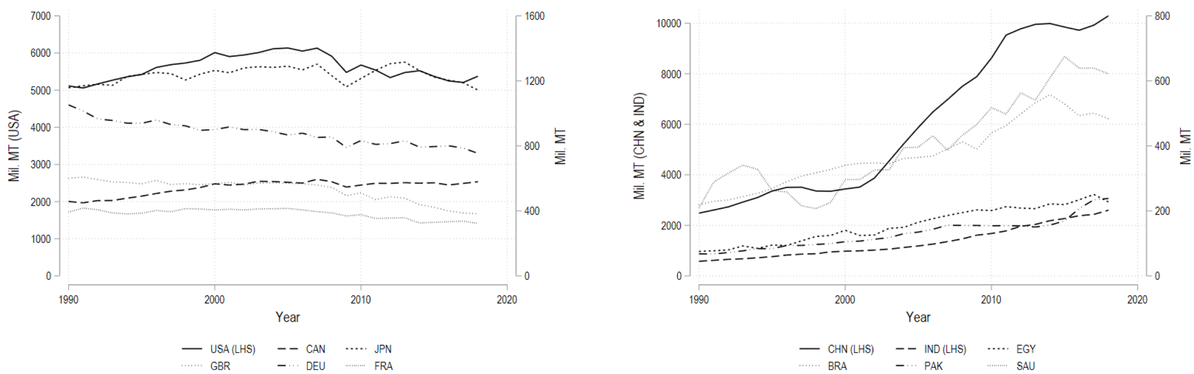


Notes: This figure depicts total global emissions of carbon dioxide in millions of metric tons. Data on emissions are sourced from the Global Carbon Project.

Figure 4: Trends in Territorial CO_2 Emissions, 1990-2018

(a) Annex B Countries

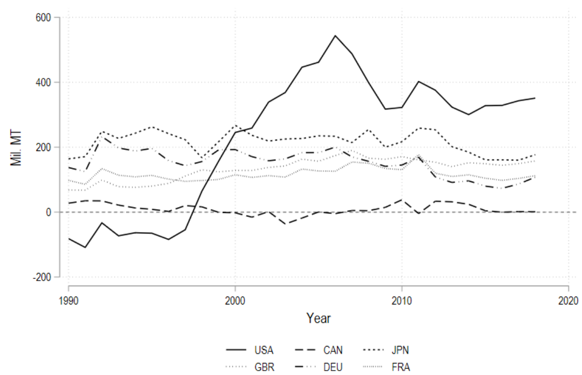
(b) Non-Annex B Countries



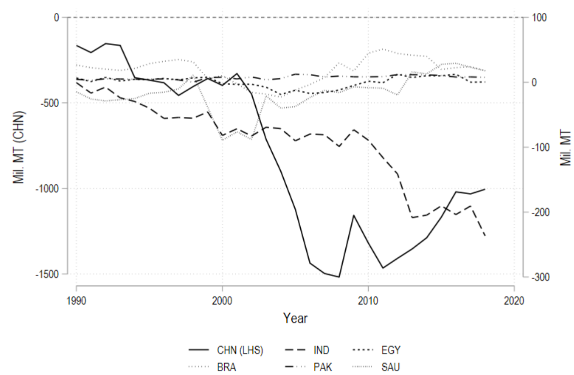
This figure plots trends in territorial emissions of CO_2 between 1990-2018. Panel 4(a): territorial emissions for select countries listed in Annex B of the Kyoto Protocol. Panel 4(b): territorial emissions for select countries not listed in Annex B of the Kyoto Protocol. Canada and Japan both withdrew from the Kyoto agreement, but not until 2011 which is why we assign them to the "Annex B" group.

Figure 5: Trends in Net CO_2 Emissions, 1990-2018

(a) Annex B Countries



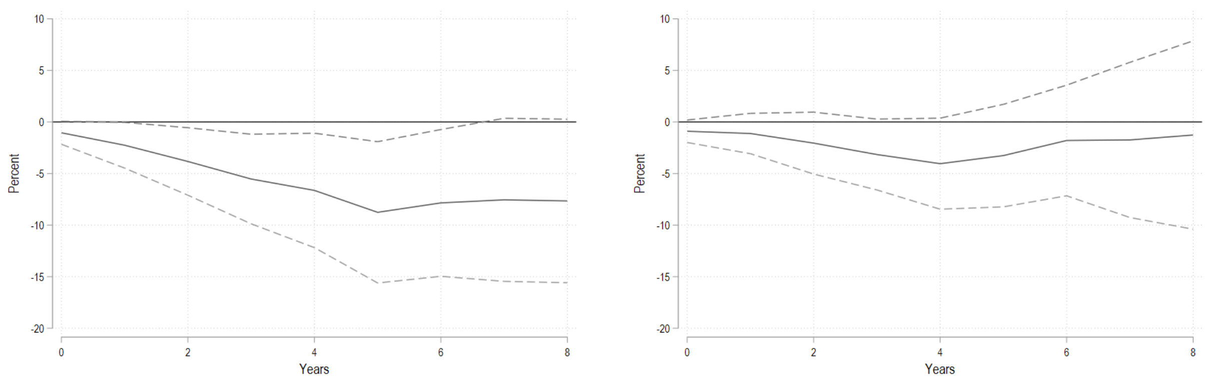
(b) Non-Annex B Countries



This figure plots trends in net emissions of CO_2 between 1990-2018. Panel 4(a): net emissions for select countries listed in Annex B of the Kyoto Protocol. Panel 4(b): net emissions for select countries not listed in Annex B of the Kyoto Protocol. Canada and Japan both withdrew from the Kyoto agreement, but not until 2011 which is why we assign them to the "Annex B" group. Net emissions are defined as the difference between consumption emissions and territorial emissions. A value above zero indicates that emissions produced by domestic demand were higher than those produced within the country.

Figure 6: Dynamic Effects of Carbon Taxation on Emissions

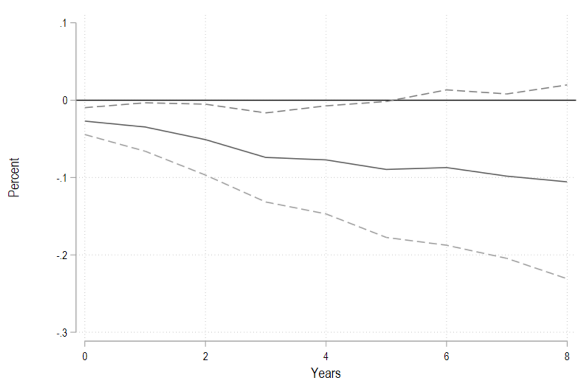
(a) Territorial Emissions (b) Consumption Emissions



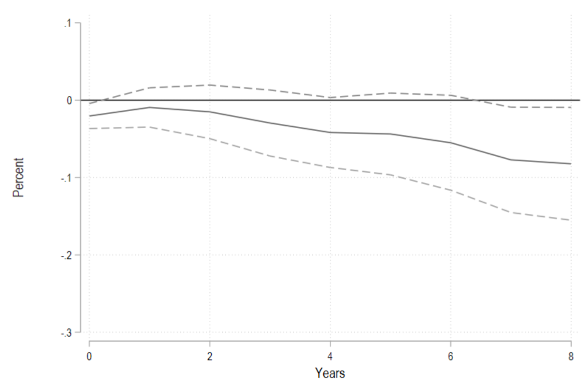
Notes: This figure plots impulse response functions capturing the dynamic effects of carbon tax implementation on territorial (6(a)) and consumption (6(b)) emissions from model (1) estimated via OLS. The distinction between territorial and consumption emissions is described in detail in Section 2. The solid line plots estimates of β^h for each horizon where the policy variable, $\tau_{i,t}$, is a dummy variable equal to one if a country has a carbon tax in a particular year and zero otherwise. The dashed lines represent 90% confidence intervals where the standard errors have been clustered at the country level (the level of treatment). The sample consists of 54 countries between the years 1992-2018 as described in Section 2.

Figure 7: Dynamic Effects of Carbon Tax Prices on Emissions

(a) Territorial Emissions

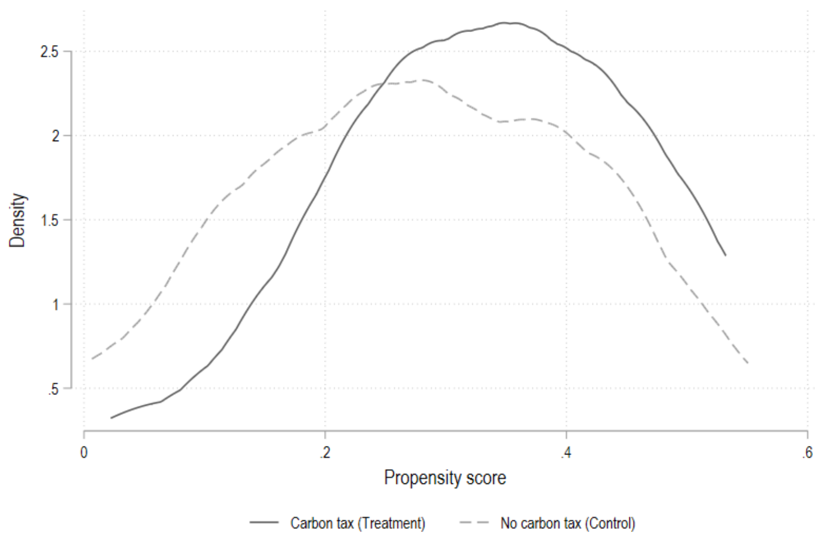


(b) Consumption Emissions



Notes: This figure plots impulse response functions capturing the dynamic effects of carbon tax implementation on territorial (7(a)) and consumption (7(b)) emissions from model (1) estimated via OLS. The distinction between territorial and consumption emissions is described in detail in Section 2. The solid line plots estimates of β^h for each horizon where the policy variable, $\tau_{i,t}$, is equal to the implied price of one ton of carbon in 2018 US dollars from carbon taxation in a country in a particular year and zero otherwise. The dashed lines represent 90% confidence intervals where the standard errors have been clustered at the country level (the level of treatment). The sample consists of 54 countries between the years 1992-2018 as described in Section 2.

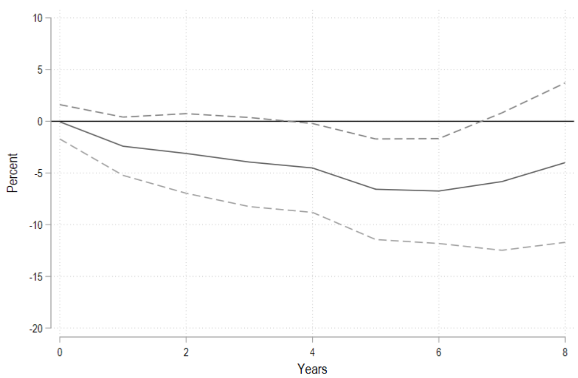
Figure 8: Distributions of Propensity Scores for Treated and Controls



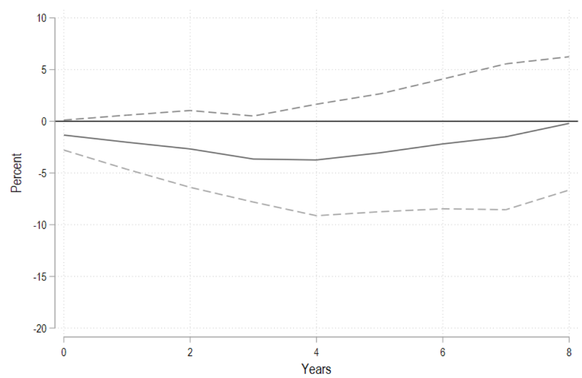
Notes: This figure plots the distributions of calculated propensity scores for countries in our sample that implemented a carbon tax (the treated) and those that did not (controls). The propensity scores are estimated via the probit model in (2).

Figure 9: Dynamic Effects of Carbon Taxation on Emissions using Inverse Propensity Score Weighting

(a) Territorial Emissions



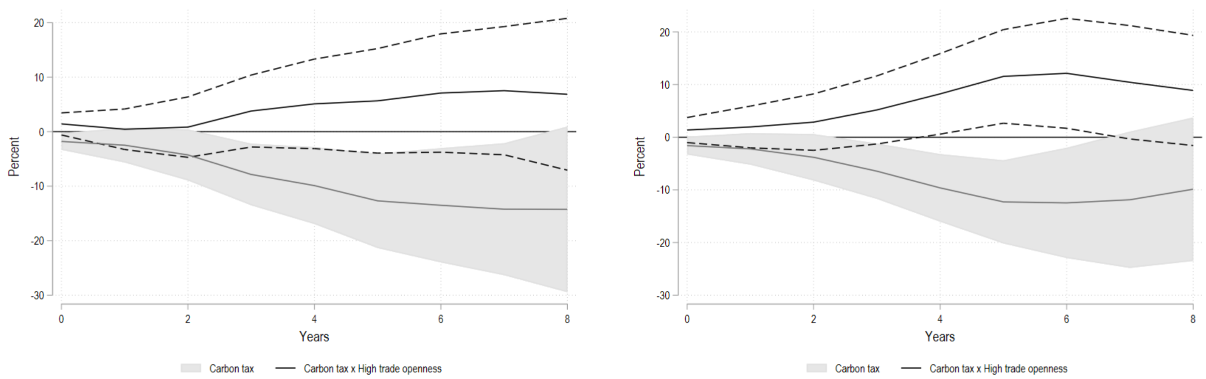
(b) Consumption Emissions



Notes: This figure plots impulse response functions capturing the dynamic effects of carbon tax implementation on territorial (7(a)) and consumption (7(b)) emissions from model (1) estimated via OLS using the IPW method outlined in Section 5.2. The distinction between territorial and consumption emissions is described in detail in Section 2. The solid line plots estimates of β^h for each horizon where the policy variable, $\tau_{i,t}$, is a dummy variable equal to one if a country has a carbon tax in a particular year and zero otherwise. The dashed lines represent 90% confidence intervals where the standard errors have been clustered at the country level (the level of treatment). The sample consists of 54 countries between the years 1992-2018 as described in Section 2.

Figure 10: Dynamic Interaction Effect of Carbon Taxation on Emissions by Openness to Trade

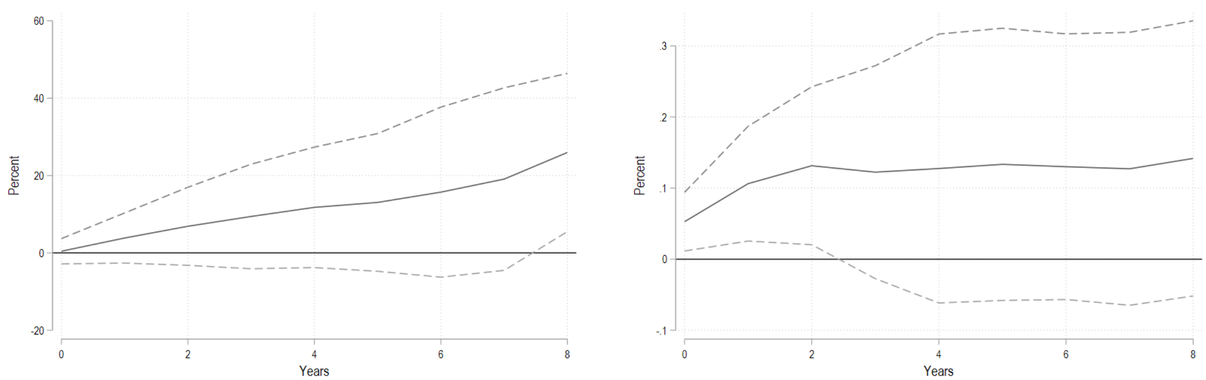
(a) Territorial Emissions (b) Consumption Emissions



Notes: This figure plots impulse response functions capturing the dynamic interaction effects of carbon tax implementation on territorial (7(a)) and consumption (7(b)) emissions by the level of trade openness. The grey area plots the 90% confidence intervals surrounding estimates of β^h from the model in equation (4) estimated using OLS. The solid line plots estimates of λ^h from (4) surrounded by 90% confidence intervals represented by the dashed lines. Standard errors are clustered at the country level (the level of treatment). The distinction between territorial and consumption emissions is described in detail in Section 2. The solid line plots estimates of λ^h for each horizon where the policy variable, $\tau_{i,t}$, is a dummy variable equal to one if a country has a carbon tax in a particular year and zero otherwise. The sample consists of 54 countries between the years 1992-2018 as described in Section 2.

Figure 11: Dynamic Effects of Carbon Taxation and Prices on Imports

(a) Carbon Tax Dummy (b) Carbon Price



Notes: This figure plots impulse response functions capturing the dynamic effects of carbon tax implementation (11(a)) and pricing (11(b)) on imports estimated via OLS. The solid line plots estimates of β^h for each horizon where the policy variable, $\tau_{i,t}$, is a dummy variable equal to one if a country has a carbon tax in a particular year and zero otherwise (11(a)), or the implied price of one ton of carbon in 2018 US dollars from carbon taxation in a country in a particular year and zero otherwise (11(b)). The dashed lines represent 90% confidence intervals where the standard errors have been clustered at the country level (the level of treatment). The sample consists of 54 countries between the years 1992-2018 as described in Section 2.

Table 1: Descriptive Statistics, 2018

	All	CO2 Tax	No CO2 Tax	p-value
Population (mil.)	107.52	42.14	135.06	.24
GDP per capita (thsd. 2015 USD)	26.11	34.12	22.75	.07
Share advanced economies	.48	.63	.42	.18
CO2 Emissions (metric tons)	597.56	233.9	750.69	.27
CO2 Emissions per capita (metric tons)	7.13	5.59	7.78	.12
N	54	16	38	.

A Data

Table A1: Data Overview

Variable	Source	Notes
Territorial CO_2 emissions	Global Carbon Project	Carbon dioxide emissions from the use of coal, oil and gas (combustion and industrial processes), the process of gas flaring and the manufacture of cement attributed to the country in which they physically occur. See Andrew and Peters (2021) for more information.
Consumption CO_2 emissions	Global Carbon Project	Carbon dioxide emissions from the use of coal, oil and gas (combustion and industrial processes), the process of gas flaring and the manufacture of cement occurring anywhere in the world attributed to the country in which goods and services are consumed. See Andrew and Peters (2021) for more information.
Real GDP per capita	World Bank WDI	GDP in constant prices divided by population.
Population	World Bank WDI	Population in millions.
Imports	IMF DOTS	
Trade openness	IMF DOTS & World Bank WDI	Sum of total exports and imports divided by GDP.
Carbon tax dummy	World Bank Carbon Pricing Dashboard	Dummy variable equal to one if a country has a carbon tax in a particular year and zero otherwise.
Carbon price	World Bank Carbon Pricing Dashboard	2018 USD price per ton of carbon implied by a carbon tax in each country in each year.

Notes: IMF DOTS = IMF Direction of Trade Statistics. World Bank WDI = World Bank World Development Indicators. PRS ICRG = PRS Group International Country Risk Guide.

Table A2: Countries Included in the Sample

OECD	Non-OECD
Australia	Argentina
Austria	Brazil
Belgium	Bulgaria
Canada	China
Chile	Colombia
Czech Republic	Croatia
Denmark	Cyprus
Estonia	Hong Kong
Finland	India
France	Indonesia
Germany	Malaysia
Greece	Malta
Hungary	Peru
Ireland	Philippines
Israel	Romania
Italy	Russia
Japan	Saudi Arabia
Latvia	Singapore
Lithuania	South Africa
Luxembourg	Thailand
Mexico	
Netherlands	
New Zealand	
Norway	
Poland	
Portugal	
Slovakia	
Slovenia	
South Korea	
Spain	
Sweden	
Switzerland	
Turkey	
United Kingdom	
United States	

Notes: OECD membership as of 2018.

B Additional Tables

Table B1: Dynamic Effects of Carbon Taxation and Pricing on Territorial Emissions

	(1) Log territorial emissions	(2) Log territorial emissions	(3) Log territorial emissions	(4) Log territorial emissions	(5) Log territorial emissions	(6) Log territorial emissions
= 1 if Carbon Tax	-0.023	-0.055**	-0.078*			
	(0.013)	(0.026)	(0.043)			
Carbon Tax Rate				-0.000*	-0.001**	-0.001
				(0.000)	(0.000)	(0.001)
Log GDP per capita	0.152	0.168	0.126	0.147	0.157	0.120
	(0.145)	(0.233)	(0.342)	(0.145)	(0.234)	(0.342)
Log GDP per capita ^{2}	-0.011	-0.015	-0.018	-0.011	-0.014	-0.018
	(0.009)	(0.014)	(0.020)	(0.009)	(0.014)	(0.020)
Log population	-0.142***	-0.224***	-0.272**	-0.140***	-0.217***	-0.271**
	(0.045)	(0.078)	(0.125)	(0.044)	(0.076)	(0.124)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Horizon	1	3	6	1	3	6
Countries	54	54	54	54	54	54
From	1990	1990	1990	1990	1990	1990
To	2018	2016	2013	2018	2016	2013
R-squared	.116	.146	.219	.115	.145	.218
N	1566	1458	1296	1562	1456	1296

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B2: Dynamic Effects of Carbon Taxation and Pricing on Consumption Emissions

	(1) Log consumption emissions	(2) Log consumption emissions	(3) Log consumption emissions	(4) Log consumption emissions	(5) Log consumption emissions	(6) Log consumption emissions
= 1 if Carbon Tax	-0.011	-0.032	-0.018			
	(0.012)	(0.021)	(0.033)			
Carbon Tax Rate				-0.000	-0.000	-0.001
				(0.000)	(0.000)	(0.000)
Log GDP per capita	0.192*	0.273	0.433	0.189*	0.271	0.426
	(0.112)	(0.200)	(0.302)	(0.113)	(0.202)	(0.302)
Log GDP per capita ^{2}	-0.012	-0.019	-0.034*	-0.012	-0.019	-0.033*
	(0.007)	(0.013)	(0.019)	(0.007)	(0.013)	(0.019)
Log population	-0.105**	-0.115	-0.136	-0.102**	-0.113	-0.139
	(0.049)	(0.118)	(0.230)	(0.048)	(0.118)	(0.230)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Horizon	1	3	6	1	3	6
Countries	54	54	54	54	54	54
From	1991	1991	1991	1991	1991	1991
To	2017	2015	2012	2017	2015	2012
R-squared	.128	.155	.225	.128	.154	.226
N	1458	1350	1188	1455	1350	1188

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B3: Dynamic Effects of Carbon Taxation and Pricing on Territorial Emissions using Inverse Propensity Weighting

	(1) Log territorial emissions	(2) Log territorial emissions	(3) Log territorial emissions	(4) Log territorial emissions	(5) Log territorial emissions	(6) Log territorial emissions
= 1 if Carbon Tax	-0.024	-0.039	-0.067**			
	(0.017)	(0.026)	(0.031)			
Carbon Tax Rate				-0.001*	-0.001**	-0.001*
				(0.000)	(0.000)	(0.001)
Log GDP per capita	-0.193	-0.226	-0.578*	-0.202	-0.241	-0.585*
	(0.183)	(0.228)	(0.300)	(0.185)	(0.230)	(0.303)
Log GDP per capita ^{2}	0.011	0.012	0.026	0.012	0.012	0.027
	(0.010)	(0.013)	(0.017)	(0.010)	(0.013)	(0.017)
Log population	-0.205**	-0.335**	-0.246**	-0.201**	-0.328**	-0.244**
	(0.083)	(0.126)	(0.108)	(0.081)	(0.125)	(0.105)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Horizon	1	3	6	1	3	6
Countries	54	54	54	54	54	54
From	1990	1990	1990	1990	1990	1990
To	2018	2016	2013	2018	2016	2013
R-squared	.323	.404	.279	.324	.405	.279
N	1566	1458	1296	1562	1456	1296

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B4: Dynamic Effects of Carbon Taxation and Pricing on Consumption Emissions using Inverse Propensity Weighting

	(1) Log consumption emissions	(2) Log consumption emissions	(3) Log consumption emissions	(4) Log consumption emissions	(5) Log consumption emissions	(6) Log consumption emissions
= 1 if Carbon Tax	-0.020	-0.037	-0.022			
	(0.016)	(0.025)	(0.038)			
Carbon Tax Rate				-0.000	-0.000	-0.001
				(0.000)	(0.000)	(0.001)
Log GDP per capita	0.236***	0.400***	0.421*	0.235***	0.402***	0.415*
	(0.056)	(0.110)	(0.210)	(0.061)	(0.115)	(0.211)
Log GDP per capita ^{2}	-0.016***	-0.029***	-0.035***	-0.016***	-0.029***	-0.035***
	(0.003)	(0.006)	(0.012)	(0.003)	(0.006)	(0.012)
Log population	-0.127***	-0.117	-0.050	-0.119***	-0.110	-0.053
	(0.041)	(0.104)	(0.209)	(0.040)	(0.104)	(0.209)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Horizon	1	3	6	1	3	6
Countries	54	54	54	54	54	54
From	1991	1991	1991	1991	1991	1991
To	2017	2015	2012	2017	2015	2012
R-squared	.313	.352	.378	.313	.351	.379
N	1458	1350	1188	1455	1350	1188

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B5: Dynamic Effects of Carbon Taxation and Pricing on Imports

	(1) Log imports	(2) Log imports	(3) Log imports	(4) Log imports	(5) Log imports	(6) Log imports
= 1 if Carbon Tax	0.038	0.094	0.157			
	(0.039)	(0.082)	(0.134)			
Carbon Tax Rate				0.001**	0.001	0.001
				(0.000)	(0.001)	(0.001)
Log GDP per capita	0.231	0.607*	0.697	0.247	0.612*	0.701
	(0.165)	(0.314)	(0.473)	(0.162)	(0.314)	(0.470)
Log GDP per capita ^{2}	-0.016	-0.045**	-0.062**	-0.017	-0.046**	-0.062**
	(0.011)	(0.021)	(0.031)	(0.011)	(0.021)	(0.030)
Log population	-0.051	-0.089	0.069	-0.049	-0.092	0.065
	(0.052)	(0.121)	(0.286)	(0.053)	(0.123)	(0.287)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Horizon	1	3	6	1	3	6
Countries	54	54	54	54	54	54
From	1990	1990	1990	1990	1990	1990
To	2018	2016	2013	2018	2016	2013
R-squared	.499	.562	.642	.499	.561	.641
N	1535	1427	1265	1531	1425	1265

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$