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July 2021

Centre for Climate Change Economics and Policy Working Paper No. 395
ISSN 2515-5709 (Online)

Grantham Research Institute on Climate Change and the Environment
Working Paper No. 367
ISSN 2515-5717 (Online)

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Suggested citation:
Eskander S and Fankhauser S (2021) *The impact of climate legislation on trade-related carbon emissions, 1997–2017*. Centre for Climate Change Economics and Policy Working Paper 395/Grantham Research Institute on Climate Change and the Environment Working Paper 367. London: London School of Economics and Political Science

The impact of climate legislation on trade-related carbon emissions, 1997-2017

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26 July 2021

Abstract

We present empirical evidence of the international emissions impact from climate change legislation in 98 countries between 1997 and 2017, using data from *Climate Change Laws of the World*. Unlike traditional measures of carbon leakage, we focus on net carbon imports, that is, the difference between consumption and production emissions. Using different estimation techniques, we estimate the impact on carbon intensity of two legislation variables, recent legislation (passed in the last 3 years) and older legislation (passed more than 3 years ago). We find that recent legislation reduces production emissions more than consumption emissions, while older laws have a bigger impact on consumption emissions. The combined effect of these changes on net carbon imports is very small. Overall, we find no evidence that domestic climate legislation has increased international carbon leakage over the past two decades. Indeed, in high-income countries the long-run leakage rate may even be negative.

JEL codes: F18, K32, Q54, Q56, Q58.

Keywords: climate change legislation, climate policy, carbon leakage, pollution havens, production emissions, consumption emissions.

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Acknowledgements: Fankhauser acknowledges financial support from the University of Oxford Strategic Research Fund, the Grantham Foundation for the Protection of the Environment and the UK Economic and Social Research Council (ESRC) through the Place-based Climate Action Network (PCAN). Eskander acknowledges financial support from the Faculty of Business and Social Sciences at Kingston University London. The authors also acknowledge support from the ESRC through the Centre for Climate Change Economics and Policy. We are grateful to Arlan Brucal, Roger Fouquet, Caterina Gennaioli, Joern Onken, Helena Schweiger, Sherrill Shaffer and Ranran Wang for their comments and insights.

1. Introduction

The international policy response to climate change is uneven. The three largest greenhouse gas emitters – China, the European Union and the United States – have now committed to reduce their emissions to "net zero" by the middle of the century, that is, to balance any remaining emissions with the removal of carbon from the atmosphere, for example through afforestation. Close to two thirds of global greenhouse gas emissions are now subject to a net zero emissions commitment (Black *et al.* 2021). However, there is considerable heterogeneity in the way these targets are implemented, and indeed in the degree to which they may be adhered to.

The premise of the Paris Agreement is that in time this patchwork of nationally determined contributions will add up to a climate outcome that is both equitable (reflecting countries' common but differentiated responsibilities) and aligned with the Paris objective of keeping the global temperature rise well below 2°C and ideally at 1.5°C. Once this is achieved, it can be left to the market to determine where economic activity takes place within a socially optimal, or at least politically acceptable, system of regulatory regimes.

However, in the short term there is considerable anxiety about the high level of policy heterogeneity. Environmentalists are concerned that it leads to carbon leakage, that is, the migration of high-emissions activities from relatively tight regulatory environments to more lenient jurisdictions. Industry representatives worry about competitiveness, that is, the associated loss of jobs and market share.

Policy makers have devised a host of potential measures to mitigate the real or perceived risk of carbon offshoring, including targeted policy exemptions, financial compensation (e.g., in the form of free emission allowances or tax rebates) and border carbon adjustments (Böhringer *et al.*

2012; Dröge *et al.* 2009; Fischer and Fox 2012; Martin *et al.* 2014; Schmidt and Heitzig 2014). These interventions command considerable policy attention. For example, a Carbon Border Adjustment Mechanism is a centrepiece of the European Union's climate package for 2030.

Academic interest in carbon leakage is equally extensive and as old as the literature on the economics of climate change itself (see Fankhauser (1995) for an early account). A recent systematic review by Yu *et al.* (2021) identified over 400 relevant studies. A related long-standing literature studies the "pollution haven effect" of uneven environmental regulation, often in the context of local pollution (Copeland and Taylor 2004). Research on clean innovation, in contrast, has highlighted the potential for beneficial spillover effects, which facilitate the dissemination low-carbon technologies (Aghion and Jaravel 2015; Acemoglu *et al.* 2014).

However, despite nearly three decades of analysis, there is little consensus on the likely magnitude, or indeed the sign, of carbon leakage.

This paper provides an empirical *ex post* account of the impact of national climate change policy and legislation on international carbon emissions between 1997 and 2017. We use the difference between countries' production emissions (the amount of carbon emitted within country boundaries) and consumption emissions (the amount of carbon embedded in national consumption) to derive the carbon trade balance of 98 countries, that is, the difference between their carbon imports and exports.

Methodologically, the paper draws on Eskander and Fankhauser (2020), who use a similar approach, but deal solely with production emissions. We construct a simple theoretical model where national climate legislation affects the carbon trade balance of a country in four ways: first, by reducing the carbon content of its exports; second, by changing international demand for its exports; third, by changing domestic demand for imports; and, fourth, by changing the carbon content of those imports, for example through fuel substitution or spillover effects.

We then use *Climate Change Laws of the World,*[1] a comprehensive global database of national climate change legislation, to estimate econometrically the combined impact of these factors on net carbon imports. *Climate Change Laws of the World* adopts a broad definition of climate legislation, including parliamentary acts, executive orders and policies of equivalent importance (Averchenkova *et al*. 2017).

The data have been collected over a decade (Townshend *et al.* 2011, 2013) and cover the full range of interventions that is relevant to reducing greenhouse gas emissions, from framework laws (such as, the UK *Climate Change Act*) and dedicated climate measures (e.g., New Zealand's *Climate Change Response (Emissions Trading) Amendment*) to sector policies on energy (e.g., Germany's *Renewable Energy Sources Act*), transport (e.g., Brazil's *Mandatory Biodiesel Requirements*) and forestry (e.g., the Democratic Republic of Congo's *Law on Protection of the Nature*).

The comprehensiveness and breadth of the data make them well suited to analyse the aggregate impact of all climate change measures in a country, and it gives us confidence that the relationships we find reflect the impact of law making, rather than a spurious correlation.

The paper departs from the existing carbon leakage literature by proposing a new metric for leakage rates. Carbon leakage is defined as the impact of climate policy on the import and export of carbon emissions, rather than the more customary focus on production emissions abroad (an

[1] Available at https://climate-laws.org/.

exception is Franzen and Mader 2018). We believe that this metric allows a sharper focus on what policy makers are ultimately interested in, namely the carbon emissions from actions that are under their control (domestic consumption, exports, imports), while ignoring those that are not (consumption abroad).

The paper also breaks new ground by offering an empirical *ex post* account of long-term carbon leakage at the country level, combining for the first time *Global Carbon Budget* data (Friedlingstein *et al.* 2020)[2] with global climate legislation data (*Climate Change Laws of the World;* Averchenkova *et al*. 2017). Previous attempts to estimate global leakage rates predominantly rely on *ex ante* simulation models (usually, computable general equilibrium models). There is an empirical *ex post* literature, but it has focused almost exclusively on competitiveness effects, rather than leakage, and it is mainly interested in firm-level impacts, not the aggregate, global picture (e.g., Dechezleprêtre *et al.* 2021; Naegele and Zaklan 2019).

We find that the passage of new climate change laws has had a significant and negative effect on both production emissions and consumption emissions, particularly over the longer term. The combined impact on net carbon imports (the difference between consumption and production emissions) has been small. Over the short term (within three years of passing a law) the impact is not statistically significant. Over the long term (beyond three years), we find a small *negative* leakage rate in high-income countries. The results are robust to a number of alternative specifications and the use of different estimation techniques (two-way fixed effect panel regression; generalised method of moments and Poisson pseudo-maximum likelihood estimation).

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[2] Available at www.globalcarbonproject.org.

Although the literature allows for this possibility (Acemoglu *et al.* 2014; Copeland and Taylor 2005; Gerlagh and Kuik 2014), finding negative leakage rates is unexpected. The result will require further analytical scrutiny to identify the exact drivers of the negative effect. In the meantime, we can stipulate with some confidence that domestic climate legislation has not increased international carbon leakage over the past two decades. This should allay fears in policy circles about the international impact of unilateral climate action.

The remainder of the paper proceeds as follows. Section 2 provides further background, putting the paper in the context of the existing literature on carbon leakage and setting out a simple theoretical model to guide our analysis. Section 3 introduces the empirical method, including a discussion of the data and our econometric estimation strategy. Section 4 presents the results and section 5 concludes.

2. Background

2.1 Carbon leakage channels

Domestic climate action can affect carbon emissions abroad through a variety of channels. Game-theoretic papers (e.g., Bohm 1993; Carraro and Siniscalco 1993; Nordhaus 2015) emphasise the risk of free-riding. In a global cooperation game, countries have fewer incentives to act on climate change if the worst impacts have already been prevented through the actions of others. This analytical angle has somewhat lost in prominence, perhaps because the global narrative has shifted from burden sharing to green growth opportunities (e.g., Fankhauser *et al.* 2013; Stern 2015). However, the reluctance of parties to the Paris Agreement to ratchet up their commitments (or nationally determined contributions) could arguably be interpreted through a free-rider lens.

Most other carbon leakage channels work through general equilibrium effects. In a general equilibrium context with free trade, unilateral climate policy may affect international emissions through price effects, trade effects or income effects. The first two are most widely studied and generally result in positive leakage rates, that is, an increase in international emissions.

The price effect is straightforward. A climate policy-induced reduction in the demand for carbon-intensive goods (say, for fossil fuels) in some countries could lower their global price and lead to a partial rebound in demand elsewhere (Harstad 2012; Kuik and Gerlagh 2003). The channel is similar to the mechanism that gives rise to the so-called "green paradox" (Jensen *et al.* 2015; Sinn 2012), and it requires high-regulation countries to be of sufficient size to influence international markets.

Trade effects work through changes in relative costs, rather than absolute prices. High-carbon industries that are subject to climate policy or legislation may suffer a loss of competitiveness, and carbon-intensive production may shift from highly regulated to less regulated jurisdictions. The argumentation is similar to the debate about "pollution haven" effects (Copeland and Taylor 2004; Levinson and Taylor 2008).

The magnitude of price and trade effects depends on industry structure, trade restrictions, substitution possibilities and the price elasticity of demand (Barker *et al.* 2007). The less price elastic the demand for carbon-intensive goods, the more the policy shock will be absorbed through price adjustments, rather than changes in the equilibrium quantity consumed. Differences in the price elasticity between high-carbon and low-carbon substitutes (say, between coal and gas), combined with a high elasticity of substitution, can dampen or exacerbate the effect.

Trade effects further depend on the degree to which goods of different origin are substitutes, with noticeably higher leakage rates in models that assume perfect substitution. Leakage rates are also higher if regulated firms were already less polluting before regulation kicked in (Fowlie 2009). They may increase further if there are increasing returns to scale in the high-carbon good, which producers in the under-regulated jurisdiction can start to exploit (Babiker 2005). The presence of oligopolistic market power, rather than perfect competition, may further complicate the picture (Ritz 2009).

The income effect is less well studied, but is interesting because it opens up the possibility of negative leakage rates. If unilateral action raises incomes in the non-regulating country, this may increase demand for environmental quality and therefore incentivise the non-regulating country to also reduce its emissions (Copeland and Taylor 2005).

A final effect, which may also lead to lower international emissions, is technology spillovers (Acemoglu *et al.* 2012, 2014; Aghion and Jaravel 2015; Gerlagh and Kuik 2014). In line with the Porter hypothesis (Porter and van der Linde 1995), climate policy and legislation may bestow a comparative advantage on regulated firms, which are forced to innovate and become more cost-effective. In a world that is gradually decarbonising, they will have a competitive edge. Through technology spillovers, these cleaner products and production processes may in time also be adopted by unregulated firms (contradicting in part the predictions of the pollution haven literature).

There is empirical little agreement on the relative importance of these different effects. Simulation models typically find leakage rates (defined as the ratio of the change in international and domestic emissions) in the order of 5-30 percent (Barker *et al.* 2007; Branger and and Quirion 2014; Yu *et al.* 2021), but this can fall to nearly zero or exceed 100 percent with the right combination of price elasticities, substitution effects, technology spillovers and returns to scale. Leakage rates may even turn negative.

Empirical *ex post* studies of leakage or competitiveness effects generally find a small or negligible impact (Dechezleprêtre and Sato 2017; Verde 2020), although there are some exceptions (Aichele and Felbermayer 2015). The same ambiguity is found in studies of specific sectors, such as aluminium, cement and steel, where leakage rates range from negligible (Branger *et al.* 2016; Sartor 2013) to substantial (Dröge *et al.* 2009). Further empirical validation of leakage effects is therefore valuable.

2.2 Analytical framework

Our empirical investigation is guided by a simple analytical framework for domestic and trade-related carbon emissions. The starting point is a simplified version of the standard macroeconomic expression for aggregate demand

$$Y_i = C_i + (E_i - I_i), \qquad (1)$$

where Y_i, denotes national output (or aggregate demand) in country i, C_i, is domestic consumption, E_i is exports and I_i.is imports. That is, the expression in brackets denotes the trade balance. For simplicity, we ignore investment and government consumption.

In a one-good, two-country economy, there will be a relative price π^*, which determines country i's terms of trade and ensures that aggregate demand equals aggregate supply. The components of aggregate demand depend on price in the normal way:

$$\frac{\delta C_i}{\delta \pi} = C' < 0; \quad \frac{\delta E_i}{\delta \pi} = E' < 0; \quad \frac{\delta I_i}{\delta \pi} = I' > 0 \qquad (2)$$

National consumption and international demand for exports depend negatively on price. Imports, or international supply, depend positively on the relative price of the domestic good.

We move from economic output to greenhouse gas emissions by multiplying each aggregate demand component with the relevant emissions factor. Denoting production or territorial emissions as P_i and consumption or embedded emissions as D_i, we have

$$P_i = e_i C_i + e_i E_i \qquad (3)$$

$$D_i = e_i C_i + e_f I_i \qquad (4)$$

where e_i is the emissions factor for domestically produced output and e_f is the emissions factor for imports, i.e., for production abroad. Note that imported emissions do not enter the equation for production emissions, as they will be accounted for in the country of origin. Similarly, when calculation consumption emissions, export-related emissions are accounted for in the destination country where consumption takes place.

Net carbon imports are then the difference between consumption and production emissions, or the difference in the carbon content of imports and exports

$$D_i - P_i = e_f I_i - e_i E_i \qquad (5)$$

We can now introduce changes in climate change policy and legislation. The purpose of passing a climate law in country *i* is to reduce the emissions coefficient e_i, but because emission abatement affects costs, passing the law may also change the equilibrium price π^*. Through technology spillovers or scale effects, the new law may also affect the carbon intensity of international production e_f.

Denoting the stock of climate laws in country i as L_i, we find the following impacts of an additional law on production and consumption emissions:

$$\frac{\delta P_i}{\delta L_i} = e_i'(C_i + E_i) + e_i(C_i' + E_i')\,\pi' \quad (6)$$

$$\frac{\delta D_i}{\delta L_i} = \left(e_i' C_i + e_f'\, I_i\right) + \left(e_i\, C_i' + e_f I_i'\right)\pi' \quad (7)$$

where $e_i' = \frac{\delta e_i}{\delta L_i}$, $e_f' = \frac{\delta e_f}{\delta L_i}$ and $\pi' = \frac{\delta \pi}{\delta L_i}$. Equation (6) is the impact of climate legislation on production emissions estimated by Eskander and Fankhauser (2020). The first expression measures the impact of a lower emissions intensity, that is, the partial decarbonisation of domestic consumption and exports. The second expression measures the response of domestic and international demand to the regulatory cost of climate legislation.

The same effects are at play in the effect on consumption emissions in equation (7). Domestic consumption gets part-decarbonised and the carbon intensity of imports might change indirectly through income, spillover or scale effects (first expression). Consumers respond to the higher price by reducing their consumption (second expression) and to the altered terms of trade by switching to imports, which have become relatively cheaper.

We can bring the impact of climate legislation on international emissions together by taking the difference between equations (7) and (6).

$$\frac{\delta D_i}{\delta L_i} - \frac{\delta P_i}{\delta L_i} = (e_f'\, I_i - e_i'\, E_i) + (e_f I_i' - e_i\, E_i')\pi' \quad (8)$$

Passing a climate law in country *i* has four international effects. The first two work through the change in the carbon intensity of imports and exports. Exports are decarbonised directly through the regulation of production emissions, while the carbon intensity of imports may change indirectly, through spillover or scale effects. The third and fourth effect work through changes in the terms of trade. Passing a climate law leads to a reduction in the demand for exports from country *i,* as carbon regulation has made them relatively more expensive. At the same time there may be an increase in imports, which have become relatively cheaper and gain market share at the expense of domestic output.

We do not make any *a priori* assumptions about the relative importance, and indeed in some cases the sign, of these four effects, but in the next section we will estimate their combined effect on the carbon trade balance (net carbon imports) empirically.

Before doing so, it is worth comparing our leakage measure (equations 8 and 5) to the standard metric for carbon leakage, which is typically defined as the change in international production emissions, divided by the change in domestic production emissions:

$$\Lambda_i \equiv \frac{\delta P_f}{\delta L_i} \Big/ \frac{\delta P_i}{\delta L_i} \qquad (9).$$

We can derive the expression for international production emissions, P_f, by adapting equation (3) and noting that $E_f = I_i$, i.e., the exports by the rest of the world equal the imports of country *i.*

$$P_f = e_f \, C_f + e_f \, I_i \quad (10).$$

The comparison of equations (5) and (10) reveals the philosophical difference between the two measures. The traditional leakage metric is determined heavily by the impact of domestic policies on foreign consumption (component $e_f C_f$ in equation 10). This is an outcome over which policy makers in country *i* do not, and indeed should not, have any influence. Our alternative metric ignores foreign consumption and instead emphasise the carbon content of country i's exports (component $e_i E_i$ in equation 5) over which its policy makers do have control. The new metric is therefore much more policy-relevant to decision makers in country i.

3. Empirical approach

3.1 Identification strategy

Following Eskander and Fankhauser (2020), we assume that a country's carbon emissions, under both production and consumption accounting rules, are a function of its track record in climate policy. Climate policy, in turn is codified in parliamentary acts, government edicts and executive orders, which we collectively refer to as "climate laws". In the most general model, emissions intensity (that is, carbon emissions per GDP) in year t would be a function of legal history, that is, of the climate laws passed in year $(t-1)$, $(t-2)$, $(t-3)$ and so on, each lag with a different weight to reflect the time dynamics of new laws (for example, the time it takes for regulations to take effect).

However, to avoid excessive lags we aggregate legislative history into two time periods: A short-term variable which consists of the stock of laws passed during the past three years, and a long-term variable which aggregates the number of laws that are older than three years. In other words, we are imposing identical coefficients for lags in each of these time periods. We are interested in emissions intensity, rather than absolute emissions, to control for confounding factors related to population and the economy.

Formally, we estimate different versions of the following equation:

$$y_{it} = \alpha + \beta_1 S_{it}^S + \beta_2 S_{it}^L + \gamma \boldsymbol{X}_{it} + \theta_i + \nu_t + \varepsilon_{it} \qquad (11)$$

where y_{it} represents the log of emissions intensity in country i at year t, that is $y_{it} \equiv ln(Z_{it} / Y_{it})$. We measure emissions in three different ways, $Z_{it} = \{P_{it},\ D_{it},\ D_{it}/P_{it}\}$ where P_{it} and D_{it} denote production and consumption emissions. Therefore, measures one and two concern production and consumption emissions, respectively, while the third measure produces estimates for our leakage metric, Φ_i.

On the right-hand side, $S_{it}^{S} \equiv \sum_{k=1}^{3} L_{i(t-k)}$ is the stock of laws passed in the previous three years, which measures the short-term effect of legislation, and $S_{it}^{L} \equiv \sum_{k=1}^{t-4} L_{ik} + S_{i0}$ is the stock of laws at the end of year $(t-4)$, which measures the long-term effect of legislation. S_{i0} is the stock of laws at the outset.

Vector $\boldsymbol{X}_{it}$ contains a set of control variables, introduced below. The model is completed by a full set of country and year fixed effects (θ_i and v_t) and the idiosyncratic error term ε_{it}. The country effect θ_i controls for time-invariant factors such as different socio-economic contexts, political cultures and resource endowments (e.g., solar irradiance and fossil fuel reserves). The time fixed effect v_t controls for inter-temporal trends that are uniform across countries, such as global progress in climate policy or the fall in clean technology costs.

Our main way of estimating equation (11) is two-way fixed effect (TWFE) panel regression. . This produces the clearest results and provides consistency with Eskander and Fankhauser (2020). We cluster the standard errors at the country level to address potential problems with serial correlation.

However, many macroeconomic variables are endogenous, which may result in inconsistent estimates when using TWFE (Greene 2010). To resolve this issue, we also use a two-step system Generalised Method-of-Moment (GMM) estimation procedure. GMM can control for country heterogeneity, short run time effects, and any possible endogeneity between the dependent variables and their predictors (Arellano and Bover 1995; Blundell and Bond 1998, 2000). In particular, we instrument all explanatory variables, except rule of law and the year effects, with a maximum of 1 further lag for the legislation variables and 2 further lags for the other variables.

Finally, we apply Poisson pseudo-maximum likelihood (PPML) estimation. The PPML model estimates a Poisson regression by pseudo-maximum likelihood to identify and drop regressors that may cause the nonexistence of the pseudo-maximum likelihood estimates (Silva and Tenreyro 2006, 2010). Based on the maximum-likelihood estimation method, PPML can be used for any kind of outcome variable provided that the mean function is correct (Wooldridge 1999).

3.2 Main data

The standard accounting convention for measuring the carbon output of countries is production emissions. Good data is readily available, in particular for energy-related and industrial process emissions. Consumption emissions data are less reliable and more difficult to obtain. They require the detailed modelling of economic interdependencies and supply chains, typically through input-output models, to calculate the emissions embedded in goods and services (Peters 2008).

We use data from the *Global Carbon Project*, which collects carbon budget data at the country-level for both measures (Friedlingstein *et al.* 2020). Our interest is in carbon emissions, where leakage effects are of most concern, although the database also contains information on methane and nitrous oxide. Earlier analysis has shown that most climate policies concern carbon emissions, rather than the non-CO_2 greenhouse gases (Eskander and Fankhauser 2020).

Figure 1 shows the evolution of production and consumption emissions over time for high-income countries (both OECD and non-OECD members) countries, which are typically net carbon importers, and low- and middle-income countries, which are net carbon exporters on aggregate. The net carbon imports of the two groups of countries are shown in Figure 2.

Figure 1

Figure 2

Climate Change Laws of the World includes information on climate change legislation and relevant policies for 198 jurisdictions (197 countries plus the European Union). The data are continuously updated. We use a version of the data of end-2020, when the database contained around 2,000 pieces of legislation and policies of similar standing.

Data gaps on consumption emissions and in some of the control variables mean we are focusing on 98 countries over the period 1997-2017, with the lagged variables going back further. The 98 countries were responsible for around 90 percent of global carbon emissions during this time. We are also excluding climate laws that solely deal with adaptation, leaving a total of 1,056 laws over 2,058 country-year observations (98 countries × 21 years).

The 1,056 laws cover a wide range of policy measures and they differ markedly in scope and ambition. The most comprehensive laws are overarching framework laws, aimed at creating the institutional framework for emission reductions. They typically define an emissions objective (such as net zero by 2050) and create the processes and institutions to implement it. However, the majority of climate laws are more targeted. They usually concern sector-specific interventions, in particular on energy. Tangible initiatives include carbon pricing schemes (either taxes or emissions trading systems), support for renewable energy, incentives for or regulation on energy conservation, support for low-carbon transport (e.g., emissions standards or subsidies for clean cars) and measures to combat deforestation. Since most laws deal with more than one issue and energy interventions in particular tend to have economy-wide effects, we think of both overarching and sector-specific laws as economy-wide interventions.

The number of climate laws has risen rapidly over the two decades of interest, from fewer than 80 relevant laws in our countries of interest in 1997 to over 1,000 relevant laws in 2017. In 1997 few countries had more than five climate-relevant laws, but that number has grown steadily and the most prolific climate legislators now have more than 25 relevant laws (Figure 3). For example, Brazil has 28 climate-related laws and policies and Spain has 38 (including adaptation laws, which are not included here; Eskander *et al.* 2021). About 40 percent of database entries are legislative acts, passed by parliaments, and about 60 percent are executive orders, issued by governments.

Figure 3

Our focus on national climate policy means ignoring important initiatives at the sub-national level and by non-state actors, which are often significant in countries with federal structures or where national engagement with climate change has been intermittent, such as Australia, Brazil, Canada and the United States. Conversely, in EU member states a focus on national climate policy would ignore the important role of the European Union in national climate policy. To control for this, all EU laws are added to the tally of EU member states.

3.3 Control variables

The vector of control variables, $\boldsymbol{X}_{it}$, is similar to Eskander and Fankhauser (2020) and summarised in Table 1. All explanatory variables are lagged by one period, denoted by (-1).

The first control variable concerns the effectiveness with which laws are implemented. Our chosen indicator for implementation effectiveness is the Rule of Law variable from the *Worldwide Governance Indicators*, which captures “perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the court” (Kaufman *et al.* 2010). The original scale was converted into a [0,1] range as follows: $g_{it} = \frac{g_{it}^{orig} - g_t^{min}}{g_t^{max} - g_t^{min}}$. In one of our specifications, the rule-of-law variable is interacted with the number of laws, so that the stock of law variables take the alternative form $\breve{S}_{it}^S \equiv \sum_{k=1}^{3} L_{i(t-k)} g_{i(t-k)}$ and $\breve{S}_{it}^L \equiv \sum_{k=1}^{t-4} L_{ik} g_{ik} + \breve{S}_{i0}$.

The next set of controls are economic variables. GDP per capita controls for the possibility of an environmental Kuznets curve (Stern 2004). Two further variables, import share and the size of the service sector, control for changes in economic structure that may affect the emissions profile. All three variables are taken from the World Bank’s *World Development Indicators* database.

Greenhouse gas emissions are subject to annual fluctuations, related in particular to the business cycle and weather. We control for this by including two variables that measure, respectively, the cyclical component of economic activity and deviation from average air temperature. The cyclical component of GDP is based on a Hodrick-Prescott (HP) decomposition, an established macroeconomics method to measure business cycle fluctuations, which is calculated by standard statistical packages (Hodrick and Prescott 1997). Fluctuations in air temperature are the difference between annual average temperatures and the long-term (1980-2015) average. Both temperature records come from the World Bank’s *Climate Knowledge Portal*.

4. Results

4.1 Emissions

We start by investigating the effects of climate legislation on production and consumption emissions. Dependent variables are the natural log of carbon intensity, that is, per-$ production and consumption emissions, which are denoted by $Ln(p)$ and $Ln(d)$, respectively, where $p = P/Y$ and $d = D/Y$.

Results are shown in Table 2. They are fairly consistent across the three estimation methods and in line with Eskander and Fankhauser (2020) who focused on production emissions but had a a larger panel of 133 countries. The TWFE results show a significant negative effect of both recent and older legislation on carbon intensity, that is annual emissions per GDP. With GMM and PPML the impact of laws is significant and negative only over the longer term.

As the dependent variables are in logarithmic form, the regression coefficients of interest denote semi-elasticities and can be interpreted as the marginal effects of laws on emissions: the percentage change in emissions due to an additional climate change law. In the short term (during the first three years), each new climate law reduces annual production emissions per GDP by up to 0.42% and annual consumption emissions per GDP by up to 0.38%. This is a level effect, that is, whole the emissions trajectory is shifted downward by this amount.

The long-term impact of laws, across the three estimation techniques, is a significant reduction in carbon intensity of 7.6–10.1% for production emissions and 8.8–12.3% for consumption emissions.

[Table 2]

While the differences between consumption and production emissions are small, they suggest that climate legislation has a (slightly) larger impact on production emissions in the short term, and a (slightly) larger impact on consumption emissions in the longer term. We will explore in the next section to what extend these differences translate into statistically significant leakage rates.

The results for the control variables are consistent with Eskander and Fankhauser (2020) and discussed further there. The significant rule of law variable highlights the importance of effective government for successful climate policy. We return to this issue when discussing alternative specifications below. There is an inverted u-shaped relationship between (the log of) emissions and (the log of) GDP per capita, similar to an environmental Kuznets curve. The positive correlation between emissions and the cyclical component of GDP (the HP variable) confirms that carbon emissions are more cyclically volatile than economic output, as the literature suggests (Doda 2014). Trade openness (measured through import share) is associated with higher emissions, while air temperatures are associated with a lower carbon intensity, reflecting the high importance of space heating, relative to cooling, in many countries.

4.2 Leakage

To investigate the effects of climate change legislation on carbon leakage, we use two different dependent variables. In the first specification, which we also use in the subsequent alternative configurations, the dependent variable is the logged ratio of consumption and production emissions, defined as $Ln(D/P)$. (Note that the per-$ term drops out, i.e., $D/P = d/p$). Because of the logarithmic form of the dependent variable, the regression coefficients of interest have an intuitive interpretation. They measure the percentage change in net carbon imports over the short and long run due to an additional climate change law, that is, $\left(\frac{\delta D_i}{\delta L_i}/D_i - \frac{\delta P_i}{\delta L_i}/P_i\right)$.

Because of the different denominators, the numerator of this expression does not correspond to equation (8). The terms for the carbon content of domestic consumption, $(e_i' C_i + e_i C_i' \pi')$, do not fully cancel out. To remedy this, we use a second dependent variable, which measures the difference (rather than the ratio) in consumption and production emissions. To avoid negative expressions, a constant shift variable is added, and the dependent variable becomes $ln(\bar{p} - p + d)$, where $\bar{p}$ is the maximum production emissions intensity observed over the estimating sample.

The leakage results are reported in Table 3. We find that the small differences between production and consumption emissions observed above do not translate into substantial carbon leakage rates. We do not find a statistically significant impact on net carbon imports within the first three years of passing a climate law. That is, there is no evidence of carbon leakage over the short-term.

[Table 3]

We find a significant impact of older climate laws on carbon leakage, but the effect is small and somewhat surprisingly the relationship is negative. The long-term effect of passing a new climate law is to reduce net carbon imports per GDP by 0. 07–0.22%. It appears that factors such as fuel substitution effects, technology spillovers and policy diffusion, which the literature identifies as potential sources of negative leakage but which take a while to materialise, ultimately dominate all other leakage channels (per equation 8 above).

4.3 Alternative specifications

We next consider two alternative specifications to refine our results and test their robustness. While corroborating the main results, the two alternatives offer interesting further insights into leakage patterns.

In the first alternative, we explore the role of national income levels on leakage rates. We do this by splitting the sample into 43 high-income countries and 55 low- and middle-income countries, using the standard World Bank income classification. We are interested in this distinction not least because most high-income countries are net carbon-importers, while low- and middle-income countries are net carbon exporters on aggregate (see Figure 2 above).

We find that the impact of climate legislation on production and consumption emissions is more pronounced in high-income countries, particularly in the short-term. The leakage rate is significant only in high-income countries, and it is again negative. While this reinforces our conclusion that unilateral climate policy has not increased emissions abroad, it suggests that the negative leakage rates we identified may be limited to rich countries.

[Table 4]

The second alternative specification concerns the treatment of government effectiveness. We know that the enforcement of climate laws is as important as their content. In the original specification, this is captured in the "rule of law" index (Kaufman *et al.* 2010), which enters the regression as a separate variable. In this alternative specification, we instead consider the interactions between the legislation and "rule of law" variables, similar to Eskander and Fankhauser (2020). The results are shown in Table 5. They confirm the importance of implementation, but are broadly in line with the main results.

[Table 5]

5. Conclusions

There is intense concern among policy makers about the risk of carbon leakage from unilateral climate action, but the literature offers no consensus on the importance or magnitude of this effect. *Ex ante* simulation models can produce both very high and very low leakage rates, depending on model specifications and parameter assumptions. Adopting a new definition of carbon leakage, we provide *ex post* evidence of the long-term impact of climate change policy on net carbon imports (our measure of leakage) between 1997 and 2017.

We find that the passage of new climate change laws has had a significant effect on both production and consumption emissions, but the impact on leakage rates has been small, especially in the short run (defined as the first three years a law is in effect). Over the long term, leakage rates in rich countries may have been negative. This is consistent with *ex post* studies on the impact of climate policy on competitiveness, which tend to find only small effects.

Of course, past leakage rates are not necessarily a good guide to the future impact of climate policies. The leakage rates of the future might be different from those observed over the past 20 years. A number of factors will be at play.

Most countries are expected to strengthen their climate policies over the coming decade in line with their nationally determined contributions to the Paris Agreement. This should reduce the overall heterogeneity in climate policies, as national ambitions begin to converge. Less policy divergence implies lower leakage rates, as the global playing field becomes more level.

There will be stragglers. The ratcheting up of ambitions will increase the gap between the bulk of countries, which seek to be Paris-aligned, and a smaller, but potentially important group of countries that do not. Current nationally determined contributions are still some way off from meeting the “well below 2°C” objective of the Paris Agreement. The gap in climate ambition that this opens might increase leakage to this second group of countries.

However, leakage rates are not exogenous, they are a function of carbon policy design. The leading countries on climate action are increasingly willing to put in place measures to prevent carbon leakage and mitigate competitiveness effects. Interest in border carbon adjustment mechanisms, in particular, has moved from the academic into the policy debate. To the extent that such policies are effective, this will help to reduce leakage rates.

Interest in border carbon adjustments is part of a wider shift in attitudes toward free trade, which could also affect carbon imports and exports. COVID-19 has demonstrated the potential benefits of shorter, more resilient supply-chains and the strategic importance of domestic control over key goods, such as vaccines and information technology but also clean technology. Even before the pandemic, global sentiment has become more cautious about free trade than governments have been in the past. Less trade in goods and services probably also means less trade in embedded carbon.

The overall impact of these trends could well be that carbon leakage remains modest, as it has been so far.

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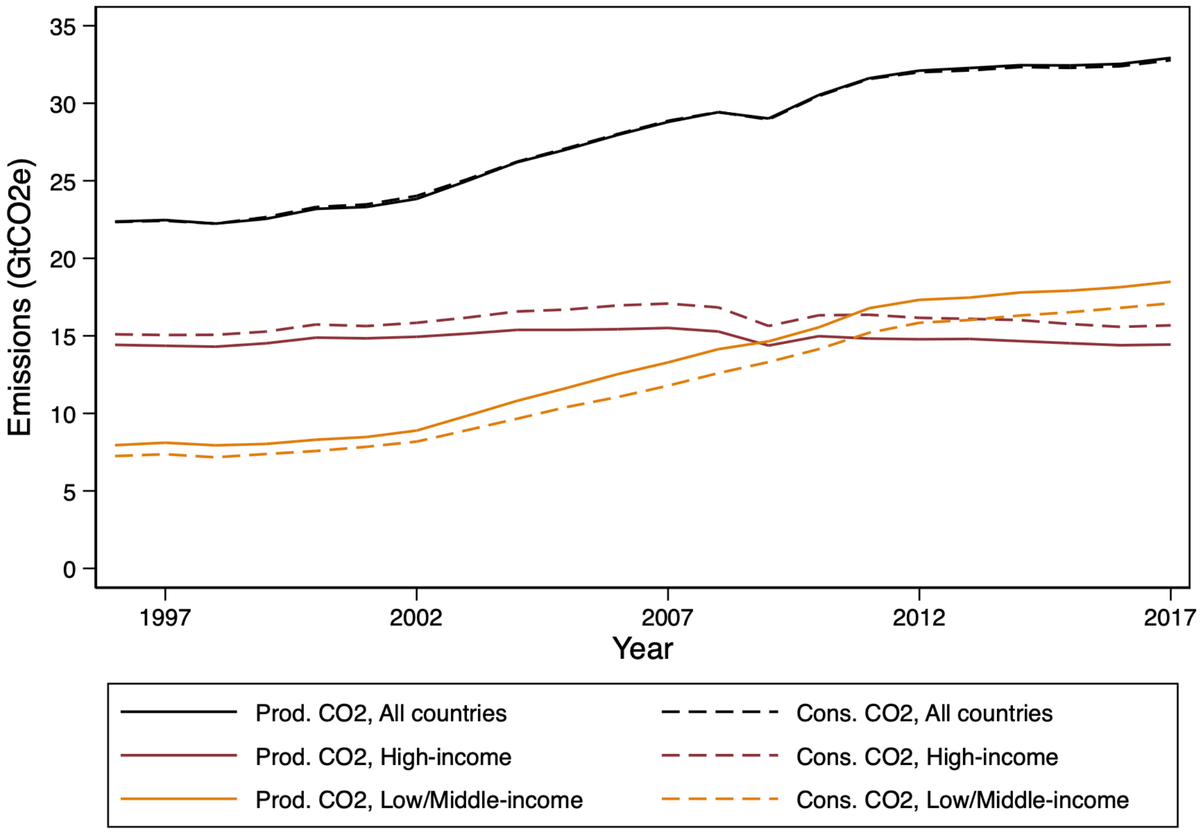
Figures

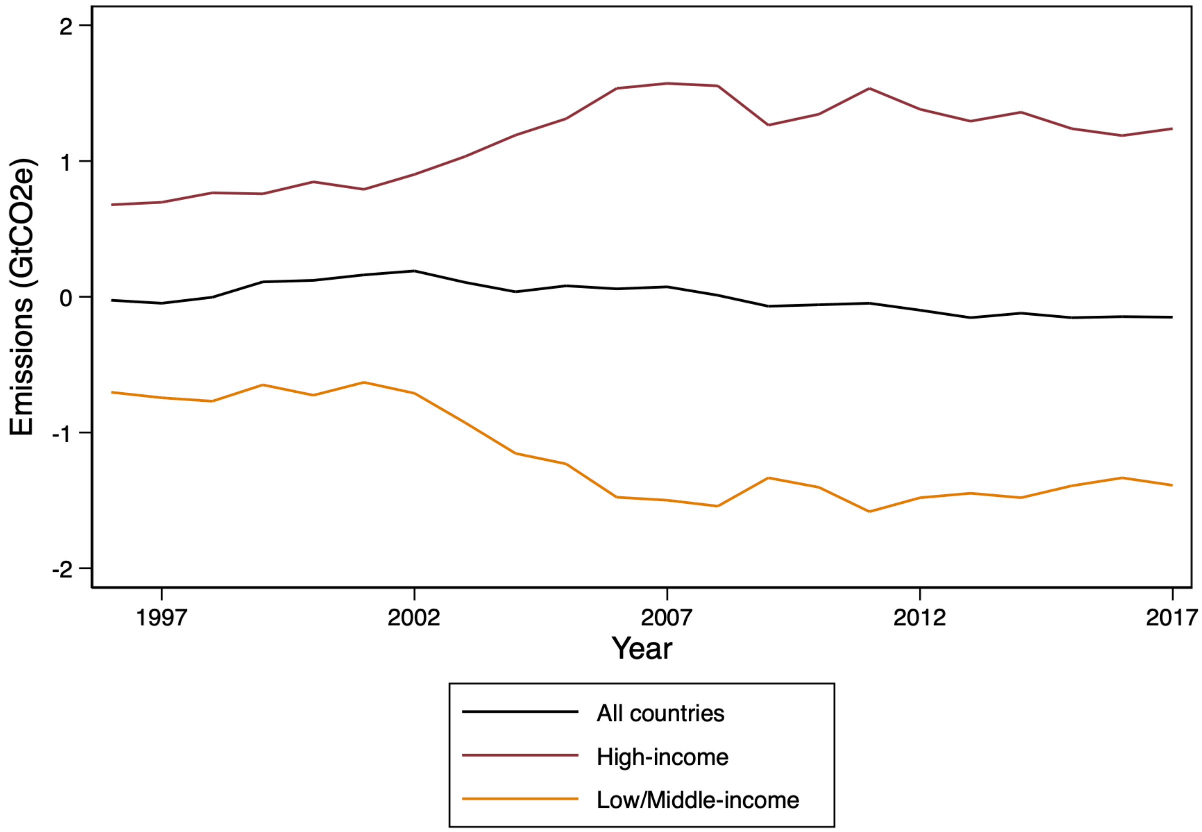
Figure 1 – Production and consumption emissions, 1997-2017



Note: The horizontal axis measures total CO_2 emissions in the country groupings of interest. Total production emissions in all countries equal total consumption emissions by definition as total carbon exports equal total carbon imports on aggregate. Data used are from 98 countries (43 high-income and 55 low/middle-income countries) over the period 1997-2017.

Source: Friedlingstein *et al.* (2019).

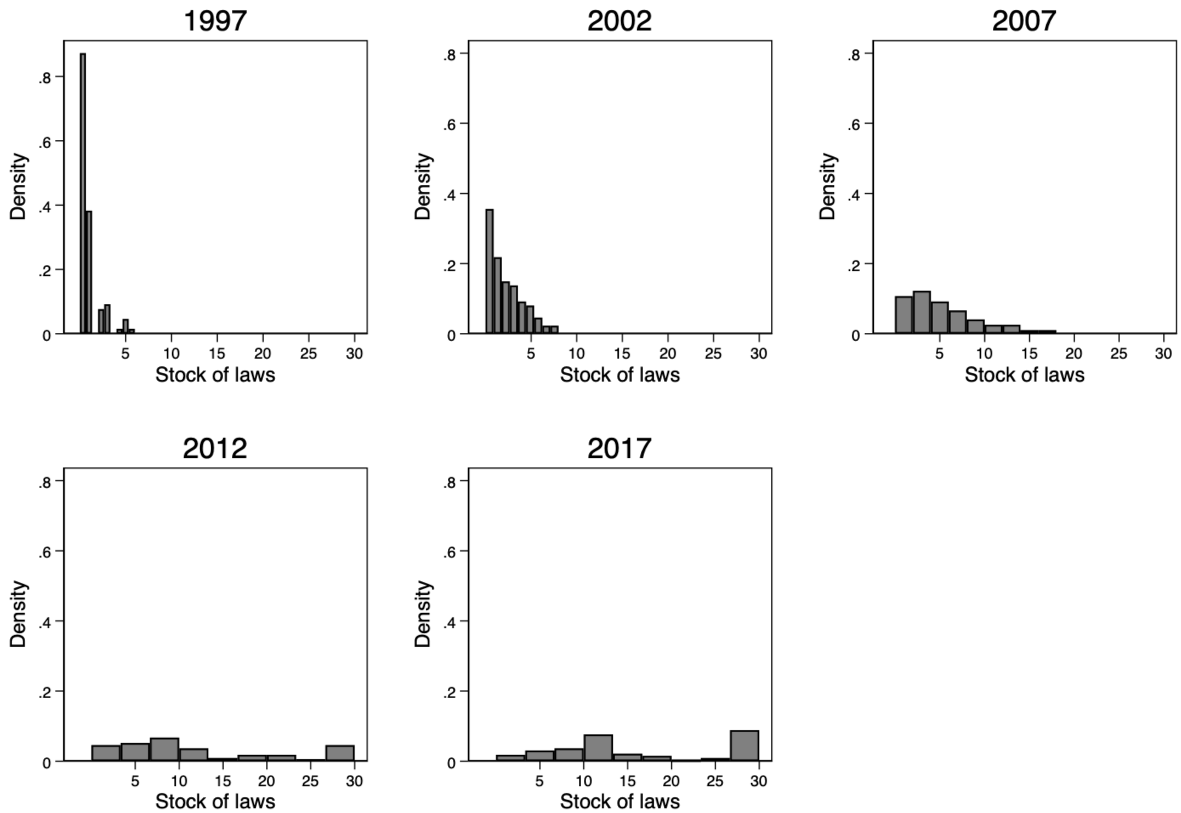
Figure 2 – Net carbon imports, 1997-2017



Note: Net carbon imports are the difference between consumption emissions and production emissions, per equation (6). Data used are from 98 countries (43 high-income and 55 low/middle-income countries) over the period 1997-2017.

Source: calculated from Friedlingstein *et al.* (2019).

Figure 3 – Climate legislation, 1997-2017



Note: The graph shows the probability distribution of the number of climate laws per country in the 98 countries (43 high-income and 55 low/middle-income countries) of interest.

Source: calculated from *Climate Laws of the World*.

Tables

Table 1 - Variables description and summary statistics

Variables	Description	Mean	Standard Deviation	Minimum	Maximum
Total production emissions	Total production emissions (Mt CO2e), includes exports and excludes imports	285.7	944.5	3.664	9,838
Total consumption emissions	Total consumption emissions (Mt CO2e), excludes exports and includes imports	285.6	888.3	3.664	8,548
p	Production emissions per $1 GDP (kg CO2e)	0.268	0.171	0.0478	1.469
d	Consumption emissions per $1 GDP (kg CO2e)	0.287	0.140	0.0533	1.367
Net carbon imports	Total carbon imports (Mt), defined as the linear difference between total consumption and production emissions	-0.0498	126.4	-1,502	502.0
$(d-p)$	Net carbon imports per $1 GDP (kg CO2), defined as the linear difference between per $1 consumption and production emissions	0.0198	0.0828	-0.557	0.526
$Ln(D/P)$	Natural logs of the ratio of consumption and production emissions	0.136	0.294	-0.916	1.649
Recent laws	Stock of mitigation laws in last 3 years in country i in year t	1.757	2.629	0	20
Older laws	Stock of mitigation laws prior to last 3 years in country i in year t	5.939	8.641	0	57
Rule of Law	Rule of law, rescaled to the range [0,1]	0.609	0.207	0.160	1
GDP	GDP per capita PPP, 2017 international $	23,633	20,829	691.2	115,415
HP filter	GDP HP filter	0.000358	0.0199	-0.158	0.106
Import share	Import as percent share of GDP	43.11	24.58	8.397	208.3
Service share	Service as percent share of GDP	54.86	9.526	21.76	79.33
Temperature	Deviation of annual temperature from long-term trend	0.336	0.482	-1.726	2.460
No. of Countries	98				
No. of Years	21				
No. of Obs.	2,058				

Notes: Summary statistics covers data from 98 countries (43 high-income and 55 low/middle-income countries) over the period 1997-2017. Emissions data comes from Friedlingstein *et al.* (2019), legislation data are obtained from Climate Change Laws of the World, and macroeconomic variables come from World Development Indicators.

Table 2 – Legislation and emissions

Variables	Two-way FE results $Ln(p)$	Two-way FE results $Ln(d)$	GMM results $Ln(p)$	GMM results $Ln(d)$	PPML results $Ln(p)$	PPML results $Ln(d)$
Recent laws (-1)	-0.0042*	-0.0038	-0.0049	-0.0032	-0.0043	-0.0031
	(0.0023)	(0.0024)	(0.0067)	(0.0070)	(0.0027)	(0.0026)
Older laws (-1)	-0.0101***	-0.0123***	-0.0076*	-0.0088*	-0.0101***	-0.0122***
	(0.0015)	(0.0017)	(0.0044)	(0.0050)	(0.0016)	(0.0018)
Rule of law (-1)	-0.2082	-0.2142	-0.3727	0.9270	-0.5273	-0.5708
	(0.2750)	(0.2452)	(0.6637)	(1.0555)	(0.4576)	(0.3867)
HP filter (-1)	0.4157*	0.7728***	-1.3712*	-0.2480	0.3585*	0.7530***
	(0.2297)	(0.2365)	(0.7285)	(0.8381)	(0.1930)	(0.2280)
Ln(GDP) (-1)	1.7862***	1.6992**	2.8895**	3.7316***	1.2412	1.0968
	(0.5112)	(0.6690)	(1.1712)	(1.3922)	(0.8109)	(0.8250)
$(Ln(GDP))^2$ (-1)	-0.1177***	-0.1139***	-0.1487**	-0.2058***	-0.0886**	-0.0803*
	(0.0259)	(0.0362)	(0.0628)	(0.0763)	(0.0397)	(0.0427)
Import share (-1)	0.0022	0.0044**	0.0045*	0.0068***	0.0024*	0.0044**
	(0.0014)	(0.0019)	(0.0024)	(0.0021)	(0.0014)	(0.0017)
Services share (-1)	-0.0042	-0.0052	-0.0041	0.0024	-0.0012	-0.0029
	(0.0032)	(0.0032)	(0.0061)	(0.0058)	(0.0044)	(0.0039)
Temperature (-1)	-0.0224**	-0.0102	0.1688	0.1135	-0.0397**	-0.0176
	(0.0107)	(0.0107)	(0.1141)	(0.0706)	(0.0179)	(0.0150)
Constant	-7.3384***	-6.7513**	-15.2250***	-19.0696***	-4.4697	-3.8036
	(2.5632)	(3.1126)	(5.4842)	(6.4589)	(4.0462)	(3.9606)
No. of Obs.	2,058	2,058	2,058	2,058	2,058	2,058
R^2 (within) / Pseudo-R^2	0.252	0.233			0.0812	0.0484
No. of countries	98	98	98	98	98	98
No. of Years	21	21	21	21	21	21
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Hansen p			0.0605	0.0657		
Hansen df			20	20		
No. of instruments			50	50		

Notes: Corrected/cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. The dependent variables are the natural log of per-$ production and consumption emissions, denoted by $Ln(p)$ and $Ln(d)$ respectively, $d = D/Y$ and $p = P/Y$. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Blundell–Bond estimation is by two-step GMM procedure. All variables, except rule of law and the year effects are instrumented with a maximum of 1 further lag for the legislation variables and 2 further lags for the other variables. The figures reported for the Hansen over-identification test, are p-values for the null hypothesis of valid instruments with χ^2. Total number of instruments is 50.

Table 3 – Legislation and carbon leakage

Variables	$Ln(D/P)$	$Ln(\bar{p} - p + d)$
Recent laws (-1)	0.0004	-0.0002
	(0.0023)	(0.0006)
Older laws (-1)	-0.0022*	-0.0007***
	(0.0013)	(0.0002)
Rule of law (-1)	-0.0060	-0.0249
	(0.2376)	(0.0443)
HP filter (-1)	0.3572	0.0791
	(0.2790)	(0.0565)
Ln(GDP) (-1)	-0.0871	0.0065
	(0.3565)	(0.0882)
$(\text{Ln(GDP)})^2$ (-1)	0.0038	0.0003
	(0.0194)	(0.0050)
Import share (-1)	0.0022	0.0004
	(0.0015)	(0.0003)
Services share (-1)	-0.0010	-0.0005
	(0.0023)	(0.0005)
Temperature (-1)	0.0121	0.0055**
	(0.0083)	(0.0025)
Constant	0.5871	0.3334
	(1.6754)	(0.3877)
No. of Obs.	2,058	2,058
R^2 (within)	0.0124	0.0258
No. of countries	98	98
No. of Years	21	21
Country FE	YES	YES
Year FE	YES	YES

Notes: Cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. The dependent variables are 1) logged ratio of production and consumption emissions, defined as $Ln(D/P)$, and 2) logged difference between per-$ consumption and production emissions, plus a constant shift variable to avoid negative expressions, that is $ln(\bar{p} - p + d)$ where $\bar{p}$ is the maximum production emissions over the estimating sample. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Table 4 – Emissions and leakage by income groups

	High-income countries			Low/Middle-income countries		
	$Ln(p)$	$Ln(d)$	$Ln(D/P)$	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Recent laws (-1)	-0.0049**	-0.0017	0.0032	0.0012	-0.0023	-0.0036
	(0.0022)	(0.0027)	(0.0024)	(0.0057)	(0.0062)	(0.0048)
Older laws (-1)	-0.0091***	-0.0114***	-0.0023	-0.0079*	-0.0090**	-0.0011
	(0.0019)	(0.0025)	(0.0017)	(0.0041)	(0.0042)	(0.0026)
Rule of law (-1)	-0.3727	-0.3877	-0.0149	-0.1683	-0.0963	0.0720
	(0.4261)	(0.3345)	(0.3372)	(0.3486)	(0.3062)	(0.3171)
HP filter (-1)	0.2088	0.6170*	0.4081	0.4830	0.8052**	0.3223
	(0.2260)	(0.3506)	(0.3634)	(0.3280)	(0.3158)	(0.3922)
Ln(GDP) (-1)	0.7427	-1.7432	-2.4859*	2.0280***	2.2168**	0.1888
	(1.6330)	(2.5118)	(1.2547)	(0.5439)	(0.8875)	(0.5822)
$(Ln(GDP))^2$ (-1)	-0.0621	0.0587	0.1208*	-0.1339***	-0.1480***	-0.0142
	(0.0809)	(0.1250)	(0.0614)	(0.0324)	(0.0513)	(0.0335)
Import share (-1)	-0.0001	0.0039	0.0040	0.0045**	0.0054***	0.0009
	(0.0016)	(0.0033)	(0.0024)	(0.0017)	(0.0018)	(0.0012)
Services share (-1)	-0.0138***	-0.0153***	-0.0015	0.0004	-0.0013	-0.0017
	(0.0042)	(0.0034)	(0.0034)	(0.0033)	(0.0035)	(0.0029)
Temperature (-1)	-0.0006	0.0085	0.0090	-0.0497**	-0.0224	0.0274*
	(0.0083)	(0.0114)	(0.0104)	(0.0205)	(0.0200)	(0.0163)
Constant	-1.1279	11.7190	12.8470*	-9.0189***	-9.4424**	-0.4235
	(8.1320)	(12.5283)	(6.4749)	(2.4132)	(3.9047)	(2.5363)
No. of Obs.	903	903	903	1,155	1,155	1,155
R^2 (within)	0.408	0.379	0.0647	0.190	0.175	0.00829
No. of countries	43	43	43	55	55	55
No. of Years	21	21	21	21	21	21
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Notes: Results based on TWFE regressions. Cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. The income classification is according to the World Bank. There are 43 high-income and 55 low/middle-income countries in the sample. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1).

Table 5 – Emissions, leakage and implementation quality

Variables	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Recent laws (-1) × Rule of law (-1)	-0.0067**	-0.0054*	0.0012
	(0.0026)	(0.0028)	(0.0025)
Older laws (-1) × Rule of law (-1)	-0.0122***	-0.0147***	-0.0025
	(0.0018)	(0.0020)	(0.0017)
HP filter (-1)	0.4683**	0.8376***	0.3693
	(0.2279)	(0.2363)	(0.2862)
Ln(GDP) (-1)	1.6569***	1.5637**	-0.0933
	(0.5191)	(0.6685)	(0.3558)
$(Ln(GDP))^2$ (-1)	-0.1127***	-0.1088***	0.0039
	(0.0260)	(0.0358)	(0.0192)
Import share (-1)	0.0024	0.0046**	0.0022
	(0.0014)	(0.0019)	(0.0014)
Services share (-1)	-0.0038	-0.0048	-0.0010
	(0.0032)	(0.0032)	(0.0023)
Temperature (-1)	-0.0246**	-0.0126	0.0120
	(0.0110)	(0.0109)	(0.0084)
Constant	-6.7209**	-6.0961*	0.6248
	(2.6030)	(3.1352)	(1.6876)
No. of Obs.	2,058	2,058	2,058
R^2 (within)	0.257	0.236	0.0121
No. of countries	98	98	98
No. of Years	21	21	21
Country FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: Results based on TWFE regressions. Cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Appendix

Table A1 - Correlation Analysis

Explanatory variables	Outcome variables $Ln(p)$	$Ln(d)$	$Ln(D/P)$
Recent laws	-0.15***	-0.11***	0.12***
Older laws	-0.17***	-0.15***	0.12***
Rule of law	-0.09***	0.03	0.20***
Ln(GDP)	-0.04	0.04	0.11***
HP filter	-0.02	0.00	0.03
Import share	0.03	0.21***	0.28***
Services share	-0.17***	-0.08***	0.21***
Temperature	-0.04	-0.02	0.04*

Notes: ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Outcome variables are the per-$ production and consumption emissions, and leakage as defined in Table 1. A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Table A2 – Stationarity Tests

Variables	t-bar	t-tilde-bar	Z-t-tilde-bar	p-value
$Ln(p)$	-1.6739	-1.4670	-0.8516	0.1972
$Ln(d)$	-1.6986	-1.4970	-1.2368	0.1081
$Ln(D/P)$	-2.6640	-2.1980	-10.2303	0.0000
Recent laws				
Older laws				
Rule of laws	-1.6791	-1.5310	-1.6729	0.0472
Ln(GDP)	-0.8143	-0.7466	8.3900	1.0000
$(Ln(GDP))^2$	-0.7034	-0.6581	9.5256	1.0000
HP filter	-3.4947	-2.7326	-17.0892	0.0000
Import share	-1.7097	-1.5792	-2.2917	0.0110
Service share	-1.5277	-1.4079	-0.0932	0.4629
Temperature	-3.7763	-2.8492	-18.5844	0.0000
No. of countries	98			
No. of years	21			

Notes. Im-Pesaran-Shin unit-root test is used, where ADF regressions do not include lags. Null and alternative hypotheses, respectively, are: *Ho: All panels contain unit roots; and Ha: Some panels are stationary*. There are 98 panels and 21 periods (years).

Table A3 – Cointegration Tests

Variables	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Modified Dickey-Fuller t	-8.6381***	-7.8001***	-15.7016***
Dickey-Fuller t	-9.4216***	-8.9491***	-15.5633***
Augmented Dickey-Fuller t	-5.4044***	-3.5195***	-9.0469***
Unadjusted modified Dickey	-14.9948***	-15.4893***	-26.3402***
Unadjusted Dickey-Fuller t	-11.8023***	-11.9558***	-18.4905***
No. of countries	98	98	98
No. of years	19	19	19

Notes. Kao test for cointegration is used. Null and alternative hypotheses, respectively, are: *Ho: No cointegration; Ha: All panels are cointegrated*. There are 98 panels and 19 periods (years) for the cointegration tests.

Supplementary Materials

Figure S1 – Normality of Residuals

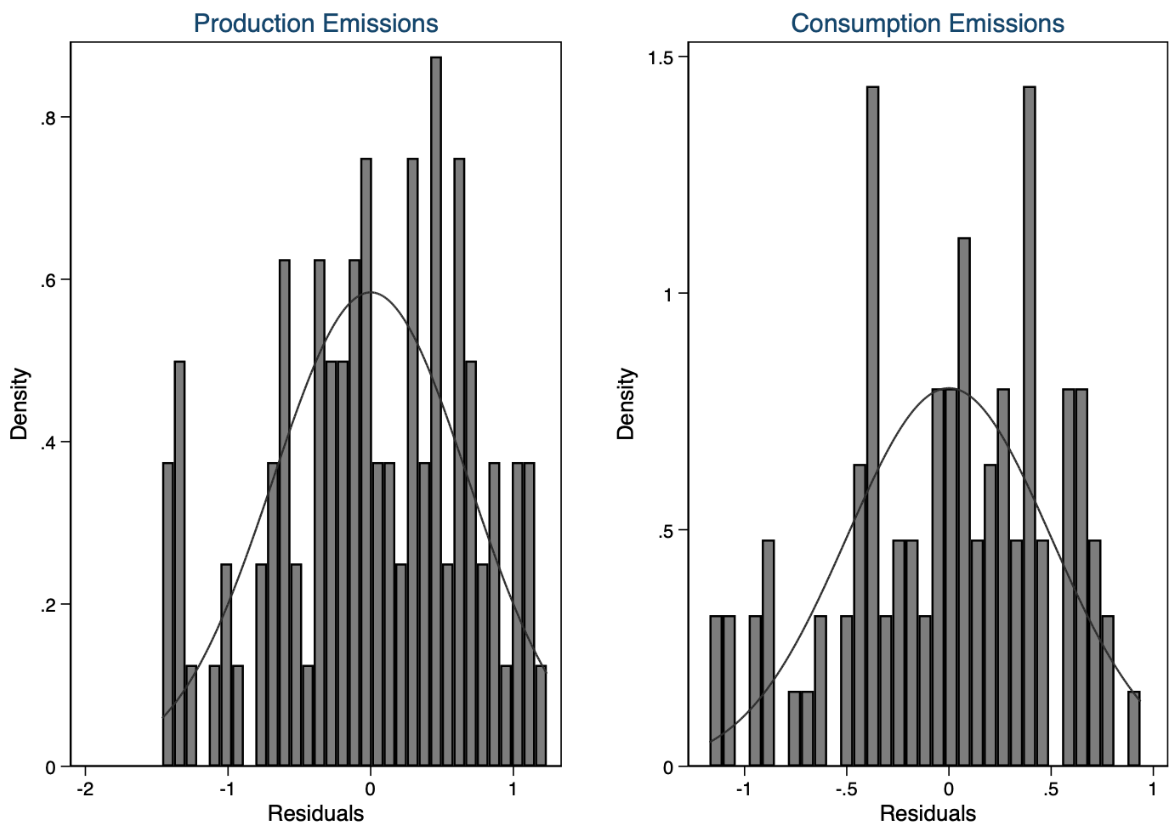


Table S1 – Alternative Definitions of Legislation

	Stock of laws			Flow of new laws		
Variables	$Ln(p)$	$Ln(d)$	$Ln(D/P)$	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Stock of laws (-1)	-0.0089***	-0.0106***	-0.0017			
	(0.0014)	(0.0016)	(0.0011)			
Flow of new laws (-1)				-0.0076**	-0.0077**	-0.0001
				(0.0029)	(0.0034)	(0.0030)
Rule of law (-1)	-0.1895	-0.1872	0.0023	-0.1324	-0.1207	0.0117
	(0.2716)	(0.2459)	(0.2402)	(0.3060)	(0.2748)	(0.2381)
HP filter (-1)	0.4027*	0.7542***	0.3515	0.4699*	0.8388***	0.3689
	(0.2299)	(0.2377)	(0.2788)	(0.2391)	(0.2367)	(0.2769)
Ln(GDP) (-1)	1.7900***	1.7046**	-0.0854	2.4860***	2.5405***	0.0545
	(0.5148)	(0.6744)	(0.3566)	(0.5108)	(0.6751)	(0.3582)
$(Ln(GDP))^2$ (-1)	-0.1178***	-0.1141***	0.0037	-0.1547***	-0.1583***	-0.0037
	(0.0261)	(0.0364)	(0.0194)	(0.0260)	(0.0365)	(0.0195)
Import share (-1)	0.0022	0.0044**	0.0022	0.0009	0.0028	0.0019
	(0.0014)	(0.0019)	(0.0015)	(0.0015)	(0.0019)	(0.0015)
Services share (-1)	-0.0041	-0.0051	-0.0010	-0.0047	-0.0058*	-0.0011
	(0.0032)	(0.0032)	(0.0023)	(0.0034)	(0.0035)	(0.0023)
Temperature (-1)	-0.0247**	-0.0136	0.0111	-0.0304***	-0.0205*	0.0099
	(0.0106)	(0.0105)	(0.0084)	(0.0111)	(0.0114)	(0.0085)
Constant	-7.3751***	-6.8043**	0.5708	-10.6191***	-10.6981***	-0.0790
	(2.5798)	(3.1412)	(1.6735)	(2.5734)	(3.1428)	(1.6799)
No. of Obs.	2,058	2,058	2,058	2,058	2,058	2,058
R^2 (within)	0.249	0.229	0.0118	0.190	0.163	0.00951
No. of countries	98	98	98	98	98	98
No. of Years	21	21	21	21	21	21
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Notes: Cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. Stock of laws refers to the total number of climate laws that are in force in a country in a given year, whereas the flow of laws refers to the number of new climate laws enacted in a country in a given year. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Table S2 – Dynamic Specifications

Variables	Two-way FE Results $Ln(p)$	$Ln(d)$	$Ln(D/P)$	GMM Results $Ln(p)$	$Ln(d)$	$Ln(D/P)$
$Ln(p)$ (-1)	0.6321***			0.9070***		
	(0.0387)			(0.0373)		
$Ln(d)$ (-1)		0.6059***			0.9641***	
		(0.0431)			(0.0429)	
$Ln(D/P)$ (-1)			0.4197***			0.7758***
			(0.0396)			(0.0909)
Recent laws (-1)	-0.0023*	-0.0017	0.0006	-0.0016	-0.0005	0.0006
	(0.0012)	(0.0012)	(0.0016)	(0.0016)	(0.0016)	(0.0027)
Older laws (-1)	-0.0037***	-0.0051***	-0.0015*	-0.0011	-0.0005	-0.0014
	(0.0007)	(0.0009)	(0.0008)	(0.0007)	(0.0009)	(0.0013)
Rule of law (-1)	-0.1591	-0.1636	-0.0035	-0.1593	-0.2226	0.1028
	(0.1146)	(0.1123)	(0.1409)	(0.1423)	(0.1520)	(0.2758)
HP filter (-1)	0.2494	0.2922	0.1347	-0.7967	-0.3438	-0.0333
	(0.1595)	(0.2117)	(0.2108)	(0.4942)	(0.3618)	(0.3605)
Ln(GDP) (-1)	0.6231***	0.5450*	-0.1142	0.1883	-0.0317	-0.2014
	(0.2170)	(0.3257)	(0.2298)	(0.1985)	(0.1857)	(0.2505)
$(Ln(GDP))^2$ (-1)	-0.0396***	-0.0368**	0.0054	-0.0083	0.0035	0.0096
	(0.0113)	(0.0179)	(0.0126)	(0.0103)	(0.0106)	(0.0132)
Import share (-1)	0.0009*	0.0015	0.0010	-0.0001	0.0001	0.0010*
	(0.0006)	(0.0009)	(0.0009)	(0.0006)	(0.0007)	(0.0005)
Services share (-1)	-0.0012	-0.0018	-0.0006	0.0004	-0.0003	0.0004
	(0.0013)	(0.0016)	(0.0016)	(0.0018)	(0.0013)	(0.0018)
Temperature (-1)	-0.0039	0.0054	0.0107	0.0218	0.0407	0.0272
	(0.0069)	(0.0086)	(0.0081)	(0.0244)	(0.0269)	(0.0337)
Constant	-2.7026**	-2.1808	0.6748	-1.0746	0.0246	0.9413
	(1.0799)	(1.5027)	(1.0673)	(0.9247)	(0.9129)	(1.1355)
No. of Obs.	2,058	2,058	2,058	2,058	2,058	2,058
R^2 (within)	0.563	0.515	0.188			
No. of countries	98	98	98	98	98	98
No. of Years	21	21	21	21	21	21
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Hansen p				0.268	0.543	0.321
Hansen df				19	19	19
No. of instruments				50	50	50

Notes: Corrected/cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. This dynamic specification includes the autoregressive term, i.e., the first lag of the dependent variable, as an additional explanatory variable. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.

Table S3 – Emissions and Leakage: OECD Countries only

Variables	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Recent laws (-1)	-0.0053*	-0.0032*	0.0021
	(0.0026)	(0.0018)	(0.0019)
Older laws (-1)	-0.0041*	-0.0079***	-0.0038*
	(0.0020)	(0.0019)	(0.0020)
Rule of law (-1)	-0.3476	-0.4108	-0.0632
	(0.3820)	(0.3829)	(0.4301)
HP filter (-1)	0.0839	-0.3950	-0.4789
	(0.4599)	(0.5866)	(0.4628)
Ln(GDP) (-1)	-2.3831	-5.2941	-2.9110**
	(3.2359)	(3.8503)	(1.3786)
$(Ln(GDP))^2$ (-1)	0.0967	0.2322	0.1355*
	(0.1652)	(0.1945)	(0.0666)
Import share (-1)	0.0004	0.0077**	0.0073**
	(0.0012)	(0.0032)	(0.0030)
Services share (-1)	-0.0048	-0.0051	-0.0003
	(0.0050)	(0.0073)	(0.0067)
Temperature (-1)	-0.0075	0.0243	0.0318**
	(0.0116)	(0.0193)	(0.0125)
Constant	13.5138	29.0917	15.5780**
	(15.6859)	(18.6299)	(7.0803)
No. of Obs.	483	483	483
R^2 (within)	0.289	0.366	0.223
No. of countries	23	23	23
No. of Years	21	21	21
Country FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: Cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 23 OECD countries over 1997-2017 forms our estimating sample in all the estimations.

Table S4 – Median regressions as robustness check

Variables	$Ln(p)$	$Ln(d)$	$Ln(D/P)$
Recent laws (-1)	-0.0042	-0.0037	0.0004
	(0.0027)	(0.0028)	(0.0044)
Older laws (-1)	-0.0101***	-0.0123***	-0.0023
	(0.0013)	(0.0014)	(0.0019)
Rule of law (-1)	-0.2065	-0.2153	-0.0058
	(0.2131)	(0.2138)	(0.3330)
HP filter (-1)	0.4292	0.7796*	0.3549
	(0.4177)	(0.4170)	(0.5760)
Ln(GDP) (-1)	1.7748***	1.6843***	-0.0712
	(0.3953)	(0.4175)	(0.6599)
$(\text{Ln(GDP)})^2$ (-1)	-0.1172***	-0.1131***	0.0029
	(0.0211)	(0.0227)	(0.0358)
Import share (-1)	0.0022*	0.0044***	0.0022
	(0.0012)	(0.0013)	(0.0019)
Services share (-1)	-0.0041	-0.0052*	-0.0009
	(0.0026)	(0.0027)	(0.0033)
Temperature (-1)	-0.0230*	-0.0104	0.0125
	(0.0132)	(0.0136)	(0.0204)
No. of Obs.	2,058	2,058	2,058
No. of countries	98	98	98
No. of Years	21	21	21
Country FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: Standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. Dependent variables are the natural log of per-$ production and consumption emissions (i.e., $Ln(p)$ and $Ln(d)$, $d = D/Y$ and $p = P/Y$), and the logged ratio of production and consumption emissions (i.e., $Ln(D/P)$), respectively. Country and Year fixed effects are included in all of the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 98 countries over 1997-2017 forms our estimating sample in all the estimations.