




The Impact of Climate Legislation on Trade-Related Carbon Emissions 1996–2018

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Abstract

We analyse the international impact on carbon emissions from national climate legislation in 111 countries over 1996–2018. We estimate trade-related carbon leakage, or net carbon imports, as the difference between consumption and production emissions. Legislation has had a significant negative and roughly similar impact on both consumption and production emissions. The net impact on trade-related emissions is therefore not statistically significant, neither in the short term (laws passed in the last 3 years) nor the long term (laws older than 3 years). We find a significant negative long-term impact on domestic emissions from laws passed by trade partners. This latter specification corresponds to the traditional definition of carbon leakage. Overall, we conclude that there has been no detrimental effect of climate legislation on international emissions.

Keywords Climate change legislation · Climate policy · Carbon leakage · Technology spillovers · Production emissions · Consumption emissions

JEL Classification F18 · K32 · Q54 · Q56 · Q58

1 Introduction

The international policy response to climate change is uneven. Over 80 percent of global greenhouse gas emissions are now subject to a net zero commitments (Hans et al. 2022), but there is considerable heterogeneity in the way individual country 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 a patchwork of nationally determined contributions will add up to a climate outcome that is both equitable (reflecting countries’

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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.

However, in the short term there is 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 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 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; Pizer and Campbell 2021; Schmidt and Heitzig 2014). These interventions command notable political 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. 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 account of the aggregate impact of climate change policy and legislation on international carbon emissions between 1996 and 2018. 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 estimate *trade-related carbon leakage* in 111 countries, that is, the difference between their carbon imports and exports. We compare trade-related leakage to the more conventional metric of *international carbon leakage*, defined as the impact of climate legislation in one country on the emissions of other countries. We calculate this latter metric inversely, by estimating the marginal impact of foreign climate laws on national emissions. Methodologically, the paper draws on Eskander and Fankhauser (2020), who use a similar approach, but deal solely with national production emissions.

The paper breaks new ground by offering a comprehensive, multi-decade empirical *ex post* assessment of carbon leakage at the country level, combining for the first time *Global Carbon Budget* data (Friedlingstein et al. 2022)¹ with global climate legislation data (*Climate Change Laws of the World*; Averchenkova et al. 2017, Townshend et al. 2011, 2013).² Previous attempts to estimate global leakage rates predominantly rely on *ex ante* simulation models (usually, computable general equilibrium models). The empirical *ex post* literature has focused almost exclusively on competitiveness effects, rather than leakage, and is mainly interested in firm-level impacts, not the aggregate, global picture (e.g., Dechezleprêtre et al. 2021; Naegele and Zaklan 2019).

The legislation data from *Climate Change Laws of the World* are well suited for aggregate analysis. The database is global and it adopts a broad definition of climate legislation, including parliamentary acts, executive orders and policies of equivalent importance. The data 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.,

¹ Available at www.globalcarbonproject.org.

² Available at <https://climate-laws.org/>.

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 gives us confidence that the relationships we find reflect the impact of law making, rather than a spurious correlation. However, we are confined to analysing the quantity of legislation, rather than its quality. We think of this as the impact of climate legislation at the extensive margin.

The paper departs from the existing literature by proposing a new metric for leakage rates, although we estimate conventional leakage for comparison. Our interest is in trade-related carbon emissions, defined as the impact of climate policy on the carbon embedded in imports and exports. The more customary focus is on the effect of policy on production emissions abroad (an exception is Franzen and Mader 2018). We believe that the trade metric offers a sharper focus on national responsibilities. National policy makers are accountable only for the emissions they have control over, and these relate to domestic consumption, exports and imports. Production emissions abroad are important from a global welfare perspective, but they are beyond the remit of domestic policy.

Using a number of estimation techniques (two-way fixed effect panel regression; generalised method of moments and Poisson pseudo-maximum likelihood estimation), we find that climate legislation has a significant and negative effect on the consumption and production emissions of the country passing the law. (The latter result replicates Eskander and Fankhauser 2020). The magnitude of the two effects is very similar, which means that the impact on trade-related emissions (the difference between consumption and production emissions) is not statistically significant. This is the case both in the short term (laws passed in the last 3 years) and the long term (laws older than 3 years). There is no evidence of trade-related carbon leakage.

In comparison, we find a significant and negative effect on domestic emissions from laws passed by trade partners, particularly over the long term. By symmetry, we conclude that climate legislation leads to a reduction (rather than an increase) in international carbon emissions. The literature allows for this possibility (Acemoglu et al. 2014; di Maria and van der Werf 2008; Gerlagh and Kuik 2014), although the overwhelming concern has been about positive leakage rates, that is an increase in foreign emissions. Understanding the exact drivers of the negative effect will therefore require further analysis.

In the meantime, we can stipulate with some confidence that domestic climate legislation has not increased international carbon emissions 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 model to guide the empirical analysis. Section 3 introduces the empirical method, including a discussion of the data and our econometric estimation strategy. Section 4 presents the results and Sect. 5 concludes.

2 Background

2.1 Carbon Leakage Channels

Domestic climate action can affect carbon emissions abroad through a multitude of channels (Jakob 2021). Early game-theoretic papers (e.g., Bohm 1993; Carraro and Siniscalco

1993) emphasise 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. Their emissions will remain high. This analytical angle has lost in prominence, but the idea of climate clubs (Nordhaus 2015) as a way to overcome free-riding continues to attract academic interest.

Most other carbon leakage channels work through general equilibrium effects, usually in a free trade context. The most widely studied general equilibrium channels are price and trade effects, both of which tend to result in positive leakage rates, that is, an increase in emissions abroad.

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 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 havens” (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).

There are two main channels through which unilateral climate policy may result in negative leakage rates, that is, a reduction in emissions abroad. They are income effects and induced innovation or technology spillover effects.

The income effect is less well studied. It occurs if unilateral action raises incomes in the non-regulating country. This may increase demand for environmental quality (a normal good) and therefore incentivise the non-regulating country to also reduce its emissions (Copeland and Taylor 2005).

Induced innovation and spillover effects have received more analytical attention (e.g., Acemoglu et al. 2012, 2014; Aghion and Jaravel 2015; Gerlagh and Kuik 2014). A policy-induced change in relative prices may not just affect competitiveness, but also induce clean innovation in other sectors (di Maria and van der Werf 2008; Golombek and Hoel 2004), which will reduce international emissions in the longer term. Knowledge spillovers allow follower firms to adopt clean best practices and move to the technology frontier. Tighter climate policy will force regulated firms to innovate and become more carbon-efficient. In a world that is gradually decarbonising, this may give them a competitive edge (Porter and van der Linde 1995).

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

Empirical *ex post* studies of leakage or competitiveness effects at the firm level 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 clearly valuable.

2.2 Analytical Framework

We set out a very simple analytical framework. Its purpose is to guide our empirical investigation into the relationship between climate legislation and international carbon emissions. More sophisticated models are available for the theoretical analysis of carbon leakage (see Sect. 2.1 above).

Since we work with aggregate country-level data, we structure the problem as a two-country, two-good model. Our country of interest is the domestic country, H , which produces a single good, good h . We think of H 's trading partners as the foreign country, F , which produces good f . By treating all trading partners as one entity, we are ignoring any third-party effects.

Both countries consume both goods and we have market equilibrium conditions

$$\begin{aligned} S_h^H(p_h, L^H) &= D_h^H(p_h, p_f, L^H) + D_h^F(p_h, p_f) \\ S_f^F(p_f) &= D_f^H(p_h, p_f, L^H) + D_f^F(p_h, p_f), \end{aligned} \tag{1}$$

where S and D denote supply and demand, respectively, and p denotes prices. Supply and demand in the home market are subject to climate change legislation, L^H . Supply-side interventions could for example take the form of a clean technology subsidy or performance standards, while demand-side interventions include measures like household energy efficiency.

From the point of view of the domestic country, foreign demand for its good is equivalent to its exports, that is $E^H = D_h^F$, while its demand for the foreign good corresponds to its imports $I^H = D_f^H$. We can further think of the relative price between the two goods as country H 's terms of trade $\pi = p_h/p_f$.

The two-country, two-good system of Eq. (1) can be solved for a set of equilibrium prices, which are a function of domestic climate legislation, the only exogenous variable: $p_h^*(L^H), p_f^*(L^H)$. The equilibrium prices in turn determine equilibrium supply

$$\begin{aligned} S_h^*(L^H) &= S_h^H(p_h^*(L^H)) \\ S_f^*(L^H) &= S_f^F(p_f^*(L^H)), \end{aligned} \tag{2}$$

equilibrium demand for good h

$$\begin{aligned} D_h^{H*}(L^H) &= D_h^H(p_h^*, p_f^*, L^H) \\ E^{H*}(L^H) &= D_h^F(p_h^*, p_f^*), \end{aligned} \quad (3)$$

and equilibrium demand for good f

$$\begin{aligned} I^{H*}(L^H) &= D_f^H(p_h^*, p_f^*, L^H) \\ D_f^{F*}(L^H) &= D_f^F(p_h^*, p_f^*) \end{aligned} \quad (4)$$

We do not make any a priori assumptions about how supply and demand depend on L^H . The purpose of climate legislation is to reduce emissions and their impact on supply and demand is a secondary effect. Nor do we make any assumptions about cross-price elasticities. Goods h and f could either be complements or substitutes.

We move from economic output to CO₂ emissions by introducing country-specific (and therefore good-specific) emissions factors e^H and e^F . Both factors are influenced by domestic climate legislation, in the case of e^H directly through policy and in the case of e^F indirectly, for example through spillover effects. Again, we do not prescribe a sign for these effects, although we can reasonably expect the domestic impact to be negative, i.e., $\partial e^H / \partial L^H \leq 0$.

Focusing on the domestic country, we define production, or territorial emissions, as:

$$P^H \equiv e^H S_h^* = e^H D_h^{H*} + e^H E^{H*} \quad (5)$$

Production emissions are simply the product of economic output (the supply of good h) multiplied by the emissions factor e^H . The second expression reminds us that output (with its associated emissions) is either consumed domestically or exported abroad.

The corresponding expression for consumption emissions is:

$$C^H \equiv e^H D_h^{H*} + e^F I^{H*}. \quad (6)$$

The first summand measures the emissions associated with the consumption of good h , which is produced domestically, and the second summand measures the emissions from consuming good f , which is produced abroad and imported.³

We are now ready to calculate carbon leakage, that is, the impact of domestic climate legislation on emissions abroad. Our main metric of interest is the effect of climate legislation on trade-related emissions, that is, the carbon content of imports and exports. By subtracting Eq. (5) from Eq. (6) we obtain the net carbon imports for country H . We then differentiate this expression with respect to domestic climate legislation to obtain our measure of trade-related carbon leakage, Γ :

$$\Gamma \equiv \frac{\partial(C^H - P^H)}{\partial L^H} = \frac{\partial e^F I^{H*}}{\partial L^H} - \frac{\partial e^H E^{H*}}{\partial L^H} \quad (7)$$

³ Kander et al. (2015) multiply exports by the carbon intensity of the destination country and imports by the domestic carbon intensity, arguing that this measures better the amount of carbon that is actually displaced. However, this specification is not suitable for our aggregate analysis.

Equation (7) tells us that domestic climate legislation affects the trade in embedded carbon in two ways. First, it may change the carbon content of domestic exports (which are equal to foreign imports), which will affect consumption emissions abroad. Second, climate legislation may change the carbon content of domestic imports (or foreign exports), which will affect production emissions abroad.

We compare the trade-related leakage metric of Eq. (7) with another measure of leakage, which is more common in the literature. International carbon leakage, Λ , is defined as the impact of domestic climate legislation on international production emissions:

$$\Lambda \equiv \frac{\partial P^F}{\partial L^H} = \frac{\partial e^F D_f^{F*}}{\partial L^H} + \frac{\partial e^F I^{H*}}{\partial L^H}, \tag{8}$$

where the expression for foreign production emissions, $P^F = e^F D_f^{F*} + e^F I^{H*}$, follows from the same logic as Eq. (5).

The comparison of Eqs. (7) and (8) reveals the philosophical difference between the two metrics. Both expressions feature the carbon content of imports (expression $e^F I^{H*}$). In the trade-related metric this is complemented by a focus on the carbon content of exports (component $e^H E^{H*}$ in Eq. 7), while the traditional leakage metric depends on the impact of climate legislation on foreign consumption (component $e^F D_f^{F*}$ in Eq. 8).

The carbon content of exports and imports is something over which domestic policy makers have authority. They may enact measures to alter the emissions profile of either or both of them. Foreign consumption, in contrast, is outside their remit. As such, we believe that the trade metric Γ offers a sharper focus on policy. It is about the emissions sources national governments have responsibility for. The traditional leakage measure Λ serves a different purpose. It takes a systems perspective and is about global environmental outcomes.

Both leakage metrics are affected by domestic climate legislation through various channels. They are listed in Table 1. Although the pertinent literature offers some pointers (see Sect. 2.1), we do not have an a priori view on the sign of any of these relationships. Instead, we will endeavour to estimate their aggregate effect empirically.

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). The list of legislation covariates would take the form:

$$\beta_t L_{it} + \beta_{t-1} L_{it-1} + \dots + \beta_0 L_{i0} \tag{9}$$

Table 1 Impact of climate legislation on trade-related emissions (Γ) and international emissions (Λ)

Impact channel	Mathematical expression for Γ	Mathematical expression for Λ
Change in carbon intensity of home-country exports (foreign country imports)	$\frac{\partial e^H}{\partial L^H} E^H$	—
Spillover effect on carbon intensity abroad	$\frac{\partial e^F}{\partial L^H} I^H$	$\frac{\partial e^F}{\partial L^H} (D_f^F + I^H)$
Price effect on international demand for the domestic good h	$e^H \frac{\partial E^H}{\partial p_h} \frac{\partial p_h}{\partial L^H}$	—
Cross-price (competitiveness) effect on demand for the foreign good f	$e^F \frac{\partial I^H}{\partial p_h} \frac{\partial p_h}{\partial L^H}$	$e^F \left(\frac{\partial D_f^F}{\partial p_h} + \frac{\partial I^H}{\partial p_h} \right) \frac{\partial p_h}{\partial L^H}$
Market adjustments in the price for the foreign good f	$\left(e^F \frac{\partial I^H}{\partial p_f} - e^H \frac{\partial E^H}{\partial p_f} \right) \frac{\partial p_f}{\partial L^H}$	$e^F \left(\frac{\partial D_f^F}{\partial p_f} + \frac{\partial I^H}{\partial p_f} \right) \frac{\partial p_f}{\partial L^H}$
Policy-induced reduction in home-country exports (foreign country imports)	$e^H \frac{\partial E^H}{\partial L^H}$	—

where L_{it} measures the number of new laws passed in country i at time t . However, to avoid excessive lags we aggregate legislative history into longer time periods. The corresponding covariates can then be interpreted as the (weighted) average impact of new laws over a period $t - k$:

$$\beta_t L_{it} + \beta_{t-1} L_{it-1} + \dots + \beta_{t-k} L_{it-k} = \beta \sum_{\tau=0}^{\tau=k} L_{i(t-\tau)} \tag{10}$$

$$\beta = \beta_t \frac{L_{it}}{\sum_{\tau} L_{i(t-\tau)}} + \beta_{t-1} \frac{L_{it-1}}{\sum_{\tau} L_{i(t-\tau)}} + \dots + \beta_{t-k} \frac{L_{it-k}}{\sum_{\tau} L_{i(t-\tau)}}. \tag{11}$$

Specifically, we estimate different versions of the following equation:

$$y_{it} = \alpha + \beta_1 S_{it}^S + \beta_2 S_{it}^L + \gamma X_{it} + \theta_i + \nu_t + \varepsilon_{it} \tag{12}$$

where y_{it} represents the log of emissions intensity in country i at year t , that is $y_{it} \equiv \ln(Z_{it}/Y_{it})$. The set $Z_{it} = \{P_{it}, C_{it}\}$ includes production emissions, P_{it} , and consumption emissions, C_{it} , the two metrics of interest. We are interested in emissions intensity, rather than absolute emissions, to control for confounding factors related to population and the economy.

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 3 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 X_{it} contains a set of control variables, introduced below. The main model is completed by a full set of country and year fixed effects (θ_i and ν_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 (e.g., industrial relations) and resource endowments (e.g., solar irradiance and fossil fuel reserves). The time fixed effect ν_i controls for inter-temporal trends that are uniform across countries, such as changes in international trade rules or the fall in clean technology costs.

The standard way of estimating Eq. (12) is two-way fixed effect (TWFE) panel regression. This specification produces the clearest results and provides consistency with Eskander and Fankhauser (2020). We cluster the standard errors at the country level to resolve potential problems with serial correlation.

If variables are endogenous, TWFE may produce inconsistent estimates (Greene 2010). To address this risk, we use a two-step system Generalised Method-of-Moment (GMM) estimation procedure as an alternative methodology. 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). We instrument all explanatory variables, except institutional quality and the year effects, with a maximum of one further lag for the legislation variables and two further lags for the other variables.

Finally, it is possible that many of the observations in our leakage variable are zero which might create the incidental variable problem. In this case, a Poisson QMLE or Poisson pseudo-maximum likelihood (PPML) can provide consistent and well-behaved estimates even when the proportion of zeros in the sample is large (Silva and Tenreiro, 2006, 2010). We therefore adopt a PPML model as an alternative estimation strategy. Specifically, we estimate a Poisson regression by pseudo-maximum likelihood to identify and drop regressors that may cause the nonexistence of the pseudo-maximum likelihood estimates. 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): Figure S2 in the supplementary materials confirms that the leakage variable is reasonably well-behaved for PPML estimation and Appendix Table 11 confirms that the PPML estimates do not suffer from the overdispersion problem.

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 emissions data at the country-level for both measures (Friedlingstein et al. 2022). 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 non-CO₂ 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), 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 Fig. 2.

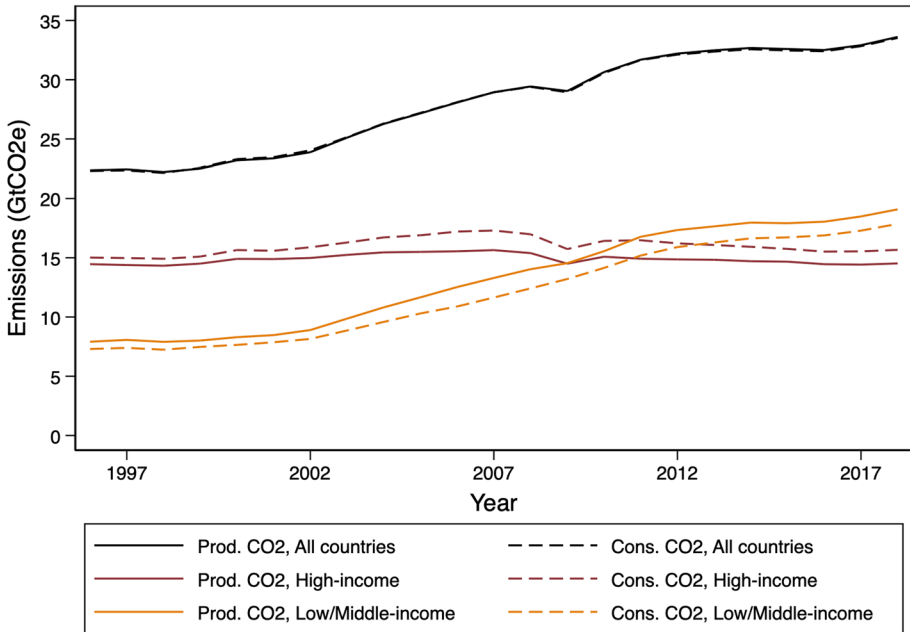


Fig. 1 Production and consumption emissions, 1996–2018. *Note:* The vertical axis measures total CO₂ emissions in the country groupings of interest. Total production emissions in all countries equal total consumption emissions by definition as total carbon exports equal total carbon imports on aggregate. Data used are from 111 countries (44 high-income and 67 low/middle-income countries) over the period 1996–2018. *Source:* Friedlingstein et al. (2022)

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 July 2022, when the database contained 2740 pieces of legislation and policies of similar standing.

Data gaps on consumption emissions and in some of the control variables mean the analysis is restricted to 111 countries over the period 1996–2018, with the lagged variables going back further. The 111 countries were responsible for over 90 percent of global carbon emissions during this time. We also exclude climate laws that solely deal with adaptation, leaving a total of 1594 mitigation laws over 2553 country-year observations (111 countries × 23 years).

The 1594 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.

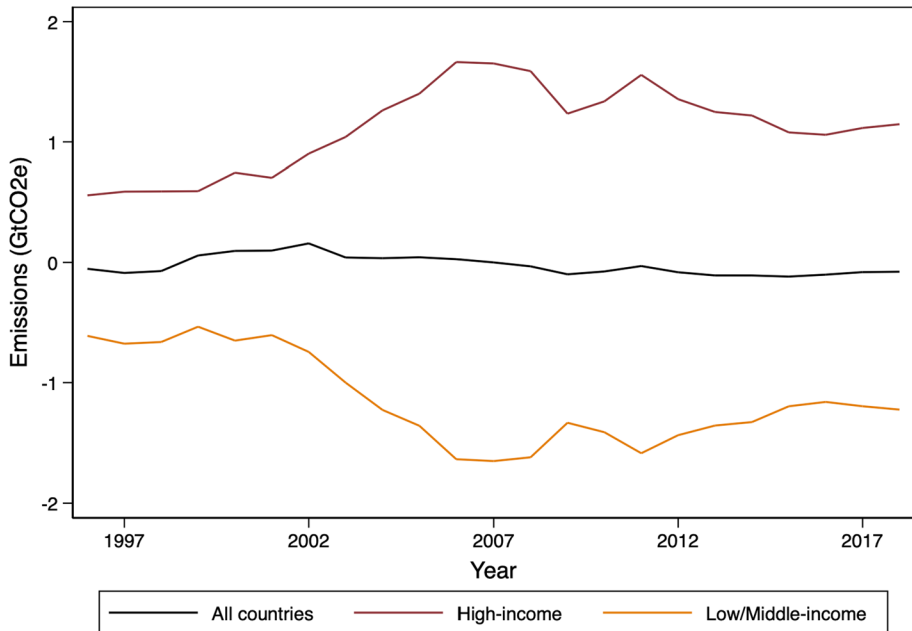


Fig. 2 Net carbon imports, 1996–2018. *Note:* Net carbon imports are the difference between consumption emissions and production emissions, per Eq. (5). Data used are from 111 countries (44 high-income and 67 low/middle-income countries) over the period 1996–2018. *Source:* calculated from Friedlingstein et al. (2022)

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 1996 to over 1000 relevant laws in 2018. In 1996 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 (Fig. 3). About 40 percent of database entries are legislative acts, passed by parliaments, and about 60 percent are executive orders, issued by governments (Eskander et al. 2021).

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.

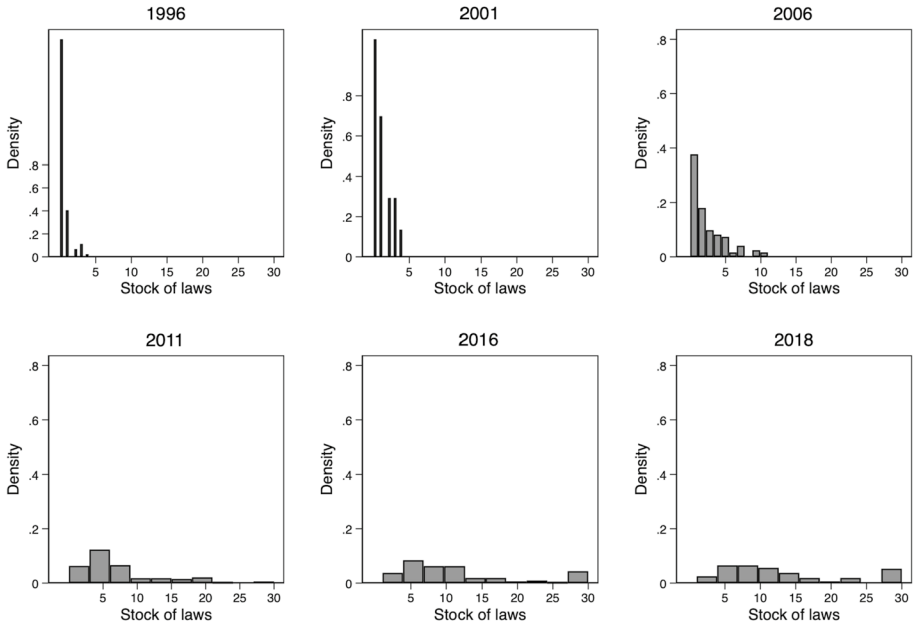


Fig. 3 Climate laws per country, 1996–2018. *Note:* The graph shows the probability distribution of the number of climate laws per country in the 111 countries (44 high-income and 67 low/middle-income countries) of interest. *Source:* calculated from *Climate Laws of the World*

3.3 Control Variables

The vector of control variables, X_{it} , is similar to Eskander and Fankhauser (2020) and summarised in Table 2. All explanatory variables are lagged by one period, denoted by (-1) in all subsequent tables.

The first control variable, institutional quality, concerns the effectiveness with which laws are implemented. We construct the institutional quality index as the average of six indices from the *Worldwide Governance Indicators: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption* (Kaufman et al. 2010). They, together, capture the strength of institutional framework of a country that is implementing a climate law. The original scale was converted into a $[0,1]$ range as follows: $g_{it} = \frac{g_{it}^{orig} - g_{it}^{min}}{g_{it}^{max} - g_{it}^{min}}$.

In one of our specifications, the institutional quality variable is interacted with the number of laws, so that the stock of law variables take the alternative form $\tilde{S}_{it} \equiv \sum_{k=1}^3 L_{i(t-k)} g_{i(t-k)}$ and $\tilde{S}_{it} \equiv \sum_{k=1}^{t-4} L_{ik} g_{ik} + \tilde{S}_{i0}$.

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 manufacturing 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.

Table 2 Variables description and summary statistics

Variables	Description	(1)	(2)	(3)	(4)
		Mean	Standard deviation	Minimum	Maximum
Total production emissions	Total production emissions (Mt CO ₂ e), includes exports and excludes imports	252.8	900.5	0.464	10,290
Total consumption emissions	Total consumption emissions (Mt CO ₂ e), excludes exports and includes imports	252.6	847.9	0.197	9285
Net carbon imports	Total carbon imports (Mt), defined as the linear difference between total consumption and production emissions	-0.223	116.9	-1518	543.5
<i>Ln(C/P)</i>	Leakage: natural logs of the ratio of consumption and production emissions	0.187	0.323	-3.431	1.504
New laws	Number of new mitigation laws enacted in country <i>i</i> in year <i>t</i>	0.608	1.355	0	13
Stock of laws	Stock of mitigation laws in country <i>i</i> in year <i>t</i>	5.090	7.336	0	56
Recent laws	Stock of mitigation laws in last 3 years in country <i>i</i> in year <i>t</i>	1.166	2.062	0	20
Older laws	Stock of mitigation laws prior to last 3 years in country <i>i</i> in year <i>t</i>	3.924	6.064	0	49
Institutional quality	Institutional quality index is the average of six indices: <i>Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption</i> . Rescaled to the range [0,1]	0.574	0.186	0.193	0.957
GDP	GDP per capita PPP, 2017 international \$	523.6	1736	1.953	19,480
HP filter	GDP HP filter	-0.000	0.0188	-0.158	0.106
Import share	Import as percent share of GDP	42.92	24.67	8.320	208.3
Manufacturing share	Manufacturing as percent share of GDP	14.33	5.650	3.420	36.76
Temperature	Deviation of annual temperature from long-term trend	0.310	0.507	-1.853	2.763
No. of Countries		111			
No. of Years		23			
No. of Obs		2553			

Summary statistics covers data from 111 countries (44 high-income and 67 low/middle-income countries) over the period 1996–2018. Emissions data comes from Friedlingstein et al. (2022), legislation data are obtained from Climate Change Laws of the World, and macroeconomic variables come from World Development Indicators

Carbon 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. Temperature data 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. The dependent variables are the natural log of carbon intensity, that is, per-\$ production and consumption emissions, which are denoted by $\ln(p)$ and $\ln(c)$, respectively, where $p = P/Y$ and $c = C/Y$.

Results are shown in Table 3. They are fairly consistent across the three estimation methods and in line with Eskander and Fankhauser (2020), who only estimate production emissions but had a larger panel of 133 countries. Climate legislation leads to a statistically significant reduction in emissions in all specifications. The effects on consumption and production emissions are similar, and the impact of older laws is generally greater than that of recent legislation.

As the dependent variables are in logarithmic form, the regression coefficients of interest denote semi-elasticities. They 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 long term (beyond the first 3 years), each new climate law reduces annual production emissions per GDP by 0.84–2.78% and annual consumption emissions per GDP by 0.91–2.61%. These are level effects, that is, the whole emissions trajectory is shifted downward by this amount.

The results for the control variables are consistent with Eskander and Fankhauser (2020) and discussed further there. 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 (but not always significant) 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). Institutional quality, trade openness (measured through import share) and economic structure (measured through manufacturing share) do not have a significant impact on emissions beyond what is captured in the fixed effect. is associated with higher emissions, and, as one would expect, the effect is greater for consumption emissions. Air temperatures above the norm are associated with a lower carbon intensity, perhaps due to lower emissions from space heating.

Table 3 Legislation and emissions

Variables	(1)		(2)		(3)		(4)		(5)		(6)	
	TWFE results		GMM results		PPML results							
	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(p)</i>	<i>Ln(c)</i>
Recent laws (-1)	-0.0094*** (0.0032)	-0.0100*** (0.0034)	-0.0310* (0.0160)	-0.0262* (0.0139)	-0.0055* (0.0033)	-0.0043 (0.0034)						
Older laws (-1)	-0.0176*** (0.0028)	-0.0201*** (0.0034)	-0.0278* (0.0144)	-0.0261** (0.0113)	-0.0084*** (0.0031)	-0.0091*** (0.0033)						
Institutional quality (-1)	-0.1990 (0.4137)	-0.2748 (0.4441)	-2.2626 (2.1681)	-1.8487 (1.7929)	0.4619 (0.4604)	0.6607 (0.5891)						
HP filter (-1)	0.3034 (0.2245)	0.7197** (0.2845)	0.5319 (1.1949)	1.1284 (1.2059)	0.1231 (0.2511)	0.3114 (0.3105)						
Ln(GDP) (-1)	4.0110*** (0.4832)	3.1970*** (0.5819)	4.1459*** (1.2529)	3.6998*** (1.2930)	3.9133*** (0.4757)	3.6192*** (0.4452)						
(Ln(GDP)) ² (-1)	-0.2210*** (0.0269)	-0.1705*** (0.0368)	-0.2294*** (0.0768)	-0.2062*** (0.0762)	-0.1984*** (0.0293)	-0.1796*** (0.0277)						
Import share (-1)	-0.0002 (0.0014)	0.0015 (0.0017)	0.0008 (0.0087)	0.0008 (0.0081)	-0.0007 (0.0026)	-0.0032 (0.0021)						
Manufacturing share (-1)	0.0029 (0.0081)	0.0049 (0.0076)	0.0052 (0.0297)	0.0080 (0.0188)	0.0154 (0.0110)	0.0123 (0.0094)						
Temperature (-1)	-0.0516*** (0.0132)	-0.0550*** (0.0138)	-0.0871 (0.0848)	-0.0726 (0.0962)	-0.0497*** (0.0172)	-0.0347*** (0.0111)						
Constant	-13.9548*** (2.2633)	-10.6648*** (2.4308)	-15.5775*** (5.0199)	-13.9426*** (5.0387)	-12.1634*** (1.8654)	-11.2150*** (1.7850)						
No. of Obs	2442	2442	2442	2442	2442	2442						
R ² (within) / Pseudo-R ²	0.457	0.294			0.991	0.990						
No. of countries	111	111	111	111	111	111						
No. of Years	22	22	22	22	22	22						

Table 3 (continued)

Variables	(1) TWFE results		(2) $Ln(c)$		(3) GMM results		(4) $Ln(c)$		(5) PPML results		(6) $Ln(c)$	
	$Ln(p)$	YES	$Ln(c)$	YES	$Ln(p)$	YES	$Ln(c)$	YES	$Ln(p)$	YES	$Ln(c)$	YES
Country FE	YES	YES	$Ln(c)$	YES		YES	YES	YES		YES	YES	YES
Year FE	YES	YES		YES		YES	YES	YES		YES	YES	YES
Income Group FE	YES	YES		YES		YES	YES	YES		YES	YES	YES
Federation FE	YES	YES		YES		YES	YES	YES		YES	YES	YES
Hansen p						0.214	0.232					
Hansen df						32	32					
No. of instruments						68	68					
AR(1)						-0.752	-2.351					
AR(2)						-0.667	-0.800					
AR(3)						-0.564	0.893					

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 $Ln(c)$, respectively, where $c = C/Y$ and $p = P/Y$. Year and country fixed effects are included in all the estimations. All control variables are lagged by one period, denoted by (-1). A balanced panel of 111 countries over 1996–2018 forms our estimating sample in all the estimations

Blundell–Bond estimation is by two-step GMM procedure. All variables, except institutional quality 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 68. PPML results follow Poisson regression with two-way fixed effects

4.2 Trade-Related Carbon Leakage

Our main leakage metric is the legislative impact on trade-related carbon emissions (expression Γ in Eq. 7). To estimate trade-related leakage we use as the dependent variable the lagged ratio of consumption to production emissions, $\ln(C/P)$. (Note that the GDP term drops out, i.e., $C/P = c/p$). Given the logarithmic form of the dependent variable, the regression coefficients of interest measure the percentage (short or long-term) change in consumption and production emissions due to an additional climate change law, that is,

$$\hat{\beta} = \left(\frac{\delta C_i}{\delta L_i} / C_i - \frac{\delta P_i}{\delta L_i} / P_i \right)^4$$

The results from the trade leakage regressions are shown in Table 4. Because the impact of legislation on consumption and production emissions is similar (Table 3), we should not expect to find a substantial effect, and indeed none of the coefficients of interest are statistically significant. This is the case both for older laws and more recent legislation and under all estimation strategies.

While the absence of a signal is more difficult to interpret than a statistically significant relationship, the robustness of the result to different estimation techniques suggests that what we find is indeed evidence of absence. We conclude that climate legislation between 1996 and 2018 has had no significant net impact, either positive or negative, on trade-related carbon emissions.

4.3 International Carbon Leakage

We compare the results for trade-related emissions, our preferred leakage metric, with the more conventional metric Λ , which measures the impact of climate laws on international production emissions.

We identify this effect inversely. Rather than measuring the impact of domestic legislation on foreign emissions, we estimate the effect of foreign legislation on domestic emissions. We postulate that at the margin the two effects are symmetrical. We focus on the climate laws passed by major export partners, on the assumption that leakage effects are strongest between countries with close trade relationships.

Table 5 shows the results of TWFE regressions of domestic emissions on the stock of foreign climate laws as an additional control variable. The most notable result is the significant negative impact, which climate legislation by the top export partner has on a country's production emissions. Each additional law by the main export partner reduces domestic emissions by 0.73% in the short term (in the first 3 years) and 0.91% in the long term (after 3 years). The impact of the top five export partners and all trade partners with an export share above 4% (assessed in 2005) is also significant, and again negative, but smaller and only in the long term.

The impact of legislation by export partners on production emissions corresponds to the traditional definition of carbon leakage (expression Λ in Eq. 8). For comparison Table 5 also reports the impact of climate legislation by import partners on consumption emissions. The two sets of results are consistent.

⁴ Using percentage, rather than absolute, differences (as in Eq. 7) means that for countries with higher consumption emissions than production emissions (as is the case in many industrialised countries) less weight is put on the legislative effect on imported emissions (that is, the first term in Eq. 7) than the effect of exported emissions (the second term in Eq. 7). The inverse is true for countries where production emissions exceed consumption emissions.

Table 4 Legislation and trade-related carbon leakage (Γ)

Variables	(1)	(2)	(3)
	TWEE results	GMM results	PPML results
Recent laws (-1)	-0.0006 (0.0018)	0.0062 (0.0071)	-0.0006 (0.0021)
Older laws (-1)	-0.0026 (0.0022)	0.0013 (0.0044)	-0.0018 (0.0024)
Institutional quality (-1)	-0.0759 (0.2157)	0.4278 (0.4202)	-0.0550 (0.2562)
HP filter (-1)	0.4164** (0.1954)	1.0373** (0.4365)	0.4586** (0.2069)
Ln(GDP) (-1)	-0.8139** (0.3398)	-0.5617 (0.3824)	-0.7563*** (0.2777)
(Ln(GDP)) ² (-1)	0.0505** (0.0244)	0.0270 (0.0224)	0.0441** (0.0196)
Import share (-1)	0.0017 (0.0012)	-0.0012 (0.0018)	0.0017 (0.0014)
Manufacturing share (-1)	0.0020 (0.0030)	0.0180 (0.0111)	0.0025 (0.0041)
Temperature (-1)	-0.0035 (0.0115)	0.0226 (0.0433)	0.0009 (0.0119)
Constant	3.2900*** (1.1466)	2.5793 (1.6304)	3.3533*** (1.0392)
No. of Obs	2442	2442	2442
R ² (within) / Pseudo-R ²	0.0249		0.0488
No. of countries	111	111	111
No. of Years	22	22	22
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Income Group FE	YES	YES	YES
Federation FE	YES	YES	YES
Hansen p		0.119	
Hansen df		32	
No. of instruments		68	
AR(1)		-2.437	
AR(2)		-2.237	
AR(3)		0.652	

Corrected/cluster-robust standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. The dependent variable is the logged ratio of consumption and production emissions ($\ln(C/P)$). Year and country fixed effects are included in all the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 111 countries over 1996–2018 forms our estimating sample in all the estimations

Blundell–Bond estimation is by two-step GMM procedure. All variables, except institutional quality 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 68. PPML results follow Poisson regression with two-way fixed effects

Although we are unable to identify individual leakage channels, the significant negative relationship suggests that income and spillover effects, which tend to be negative, are dominating price and competitiveness effects, which are more likely to be positive (see Sect. 2). The fact that the effect is stronger in the long term further supports the presence of spillover effects, which take time to materialise.

4.4 Alternative Specifications

We next perform a number of robustness checks, focusing on trade-related leakage. The additional tests confirm the main results, but also offer interesting further insights into leakage patterns.

In the first alternative specification, we explore the role of national income levels on leakage rates. We do this by splitting the sample into 44 high-income countries and 67 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 Fig. 2 above).

We find that the impact of climate legislation on production and consumption emissions is more pronounced in high-income countries (Table 6), suggesting that rich countries have perhaps taken the lead (if timidly so) on reducing carbon emissions, as the tenet of common but differentiated responsibilities demands. The leakage rates are again not statistically significant. This reinforces our conclusion that unilateral climate policy has not increased trade-related emissions, including in industrialised countries, which tend to be most concerned about the issue.

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 “institutional quality” index (Kaufman et al. 2010), which enters the regression as a separate variable. In this alternative, we instead consider the interactions between the legislation and “institutional quality” variables, similar to Eskander and Fankhauser (2020). The results are shown in Table 7. They confirm the importance of implementation, and are broadly in line with the main results.

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 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.

Focusing on trade-related carbon emissions, as well as traditional leakage metrics for comparison, we provide empirical *ex post* evidence of the short and long-term impact of climate legislation on international emissions between 1996 and 2018. We find that the passage of new climate laws has had no significant impact on trade-related carbon emissions and a negative long-term effect on international production emissions. These findings are consistent with *ex post* studies on the impact of climate

Table 5 Legislation and international carbon leakage (Λ)

Variables	(1)		(2)		(3)		(4)		(5)		(6)	
	Export destinations						Import sources					
	All major		Top-5		Top-most		All major		Top-5		Top-most	
Recent laws at export destination (-1)	-0.0015 (0.0009)	-0.0014 (0.0012)	-0.0073** (0.0031)				-0.0008 (0.0008)	-0.0009 (0.0011)			-0.0021 (0.0039)	
Older laws at export destination (-1)	-0.0025*** (0.0005)	-0.0028*** (0.0007)	-0.0091*** (0.0026)				-0.0030*** (0.0009)	-0.0039*** (0.0011)			-0.0067** (0.0026)	
Recent laws at import sources (-1)				-0.0063** (0.0030)	-0.0059* (0.0032)	-0.0062** (0.0031)	-0.0069* (0.0036)	-0.0059 (0.0036)			-0.0078** (0.0036)	
Older laws at import sources (-1)				-0.0124*** (0.0026)	-0.0127*** (0.0028)	-0.0130*** (0.0027)	-0.0145*** (0.0033)	-0.0149*** (0.0031)			-0.0166*** (0.0034)	
Institutional quality (-1)				-0.3211 (0.3949)	-0.3454 (0.3988)	-0.1896 (0.3745)	-0.2480 (0.4172)	-0.2952 (0.4050)			-0.2652 (0.4461)	
HP filter (-1)				0.1865 (0.1970)	0.2103 (0.2081)	0.2345 (0.2169)	0.7702** (0.2998)	0.7285** (0.2958)			0.7305** (0.2866)	
Ln(GDP) (-1)				3.7725*** (0.4496)	3.8468*** (0.4733)	4.1215*** (0.4252)	2.9731*** (0.5612)	2.9531*** (0.5603)			3.0150*** (0.5920)	
(Ln(GDP)) ² (-1)				-0.2045*** (0.0251)	-0.2097*** (0.0264)	-0.2265*** (0.0237)	-0.1609*** (0.0354)	-0.1587*** (0.0354)			-0.1612*** (0.0374)	
Import share (-1)				0.0008 (0.0014)	0.0003 (0.0014)	0.0006 (0.0014)	0.0025 (0.0017)	0.0026 (0.0017)			0.0023 (0.0017)	
Manufacturing share (-1)				0.0044 (0.0076)	0.0038 (0.0077)	0.0030 (0.0079)	0.0025 (0.0085)	0.0036 (0.0078)			0.0039 (0.0078)	

Table 5 (continued)

Variables	(1)		(2)		(3)		(4)		(5)		(6)	
	Export destinations		Top-5		Top-most		All major		Top-5		Top-most	
Temperature (-1)	-0.0467*** (0.0130)	-0.0466*** (0.0129)	-0.0422*** (0.0149)	-0.0426*** (0.0133)	-0.0442*** (0.0129)	-0.0487*** (0.0135)	-0.0426*** (0.0133)	-0.0442*** (0.0129)	-0.0442*** (0.0129)	-0.0442*** (0.0129)	-0.0487*** (0.0135)	-0.0487*** (0.0135)
Constant	-13.0853*** (2.1129)	-13.2919*** (2.2231)	-14.4843*** (1.9847)	-9.4048*** (2.3442)	-9.3911*** (2.3267)	-9.8002*** (2.4647)	-9.4048*** (2.3442)	-9.3911*** (2.3267)	-9.3911*** (2.3267)	-9.3911*** (2.3267)	-9.8002*** (2.4647)	-9.8002*** (2.4647)
No. of Obs	2442	2442	2442	2442	2442	2442	2442	2442	2442	2442	2442	2442
R ² (within)	0.496	0.482	0.491	0.328	0.329	0.304	0.328	0.329	0.329	0.329	0.304	0.304
No. of countries	111	111	111	111	111	111	111	111	111	111	111	111
No. of Years	22	22	22	22	22	22	22	22	22	22	22	22
Country FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Income Group FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Federation FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

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. The dependent variable is the natural log of per-\$ production emissions, denoted by $Ln(p)$ where $p = P/Y$ for export destinations and the natural log of per-\$ consumption emissions, denoted by $Ln(c)$ where $c = C/Y$ for import sources. Country and year fixed effects are included in all the estimations. All control variables are lagged by 1-period, denoted by (-1). A balanced panel of 111 countries over 1996–2018 forms our estimating sample in all the estimations

Table 6 Emissions and trade-related leakage by income groups

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	High-income countries			Low/Middle-income countries		
	$\ln(p)$	$\ln(c)$	$\ln(C/P)$	$\ln(p)$	$\ln(c)$	$\ln(C/P)$
Recent laws (− 1)	− 0.0130*** (0.0029)	− 0.0131*** (0.0027)	− 0.0001 (0.0018)	0.0059 (0.0091)	0.0062 (0.0097)	0.0004 (0.0039)
Older laws (− 1)	− 0.0145*** (0.0030)	− 0.0165*** (0.0036)	− 0.0020 (0.0022)	− 0.0101 (0.0073)	− 0.0122 (0.0086)	− 0.0021 (0.0045)
Institutional quality (− 1)	0.9742 (0.6035)	0.6764 (0.6657)	− 0.2978 (0.4402)	− 0.4549 (0.4486)	− 0.3898 (0.4686)	0.0651 (0.2516)
HP filter (− 1)	1.0450*** (0.3102)	1.3119*** (0.3444)	0.2669 (0.2569)	− 0.0761 (0.2888)	0.4524 (0.4092)	0.5285 (0.3222)
$\ln(\text{GDP})$ (− 1)	1.7360* (0.9873)	0.6484 (1.4726)	− 1.0876 (0.9624)	3.8184*** (0.6246)	2.5608** (1.1837)	− 1.2576 (0.9299)
$(\ln(\text{GDP}))^2$ (− 1)	− 0.1124** (0.0508)	− 0.0465 (0.0761)	0.0659 (0.0498)	− 0.2111*** (0.0400)	− 0.1344 (0.0817)	0.0767 (0.0654)
Import share (− 1)	− 0.0006 (0.0017)	0.0039 (0.0028)	0.0046** (0.0022)	0.0013 (0.0018)	0.0021 (0.0022)	0.0008 (0.0015)
Manufacturing share (− 1)	0.0031 (0.0154)	− 0.0056 (0.0125)	− 0.0088 (0.0059)	0.0045 (0.0071)	0.0124* (0.0067)	0.0079** (0.0039)
Temperature (− 1)	− 0.0325*** (0.0115)	− 0.0229 (0.0143)	0.0096 (0.0117)	− 0.0735*** (0.0238)	− 0.0763*** (0.0274)	− 0.0028 (0.0220)
Constant	− 2.1819 (4.6900)	2.3383 (7.0508)	4.5202 (4.5533)	− 13.5866*** (2.6272)	− 8.4828* (4.3049)	5.1038 (3.2086)
No. of Obs	968	968	968	1474	1474	1474
R ² (within)	0.315	0.259	0.108	0.314	0.146	0.0290
No. of countries	44	44	44	67	67	67
No. of Years	22	22	22	22	22	22
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Federation FE	YES	YES	YES	YES	YES	YES

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. The dependent variables are the natural log of per-\$ production and consumption emissions, denoted by $\ln(p)$ and $\ln(c)$, respectively, for emissions where $c = C/Y$ and $p = P/Y$, and the natural log of the ratio of consumption and production emissions ($\ln(C/P)$) for leakage. The income classification is according to the World Bank. There are 44 high-income and 67 low/middle-income countries over 1996–2018 in the sample. Country and year fixed effects are included in all the estimations. All control variables are lagged by one period, denoted by (−1)

policy on competitiveness, which tend to find only small effects (Dechezleprêtre and Sato 2017; Verde 2020).

While our analysis sheds important light on the sign and magnitude of actually observed leakage effects, it cannot answer the question about the likely drivers of these trends. The absence of a clearly positive effect (that is, an increase in international emissions) suggests that price and competitiveness effects (which tend to be positive)

Table 7 The impact of institutional quality

Variables	(1)	(2)	(3)
	$\ln(p)$	$\ln(c)$	$\ln(C/P)$
Recent laws (-1) × Institutional quality (-1)	-0.0164*** (0.0035)	-0.0181*** (0.0038)	-0.0017 (0.0025)
Older laws (-1) × Institutional quality (-1)	-0.0252*** (0.0036)	-0.0287*** (0.0041)	-0.0035 (0.0030)
HP filter (-1)	0.3429 (0.2176)	0.7670*** (0.2811)	0.4241** (0.1988)
$\ln(\text{GDP})$ (-1)	3.7196*** (0.4920)	2.8623*** (0.6096)	-0.8573** (0.3635)
$(\ln(\text{GDP}))^2$ (-1)	-0.2059*** (0.0271)	-0.1533*** (0.0379)	0.0526** (0.0253)
Import share (-1)	0.0003 (0.0014)	0.0020 (0.0017)	0.0017 (0.0012)
Manufacturing share (-1)	0.0030 (0.0080)	0.0050 (0.0075)	0.0020 (0.0030)
Temperature (-1)	-0.0531*** (0.0135)	-0.0570*** (0.0139)	-0.0038 (0.0116)
Constant	-12.7356*** (2.2887)	-9.2737*** (2.5144)	3.4619*** (1.2368)
No. of Obs	2442	2442	2442
R ² (within)	0.470	0.306	0.0252
No. of countries	111	111	111
No. of Years	22	22	22
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Income Group FE	YES	YES	YES
Federation FE	YES	YES	YES

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. The dependent variables are the natural log of per-\$ production and consumption emissions, denoted by $\ln(p)$ and $\ln(c)$, respectively, for emissions where $c = C/Y$ and $p = P/Y$, and the natural log of the ratio of consumption and production emissions ($\ln(C/P)$) for leakage. Country and year fixed effects are included in all the estimations. All control variables are lagged by one period, denoted by (-1). A balanced panel of 111 countries over 1996–2018 forms our estimating sample in all the estimations

may have been exaggerated, while income effects and technology spillovers (which would be negative) may have been underestimated. However, disentangling the different drivers of leakage will require more granular analysis than we offer here.

More granularity would also help to identify differences in the leakage characteristics of different policy interventions. For example, it would be interesting to explore whether price-based, technology-focused and regulatory policy interventions result in different leakage rates. Text analysis and machine learning increasingly allow a finer stratification of climate policy and legislation data, which will make it possible to answer these questions (e.g., Linsenmeier et al. 2022).

Our findings should encourage policy makers to move ahead with their emission reduction plans without undue concern about the international impact of their actions. Of course, past leakage rates are not necessarily a good guide to the future impact of climate policies. However, two factors might serve to keep leakage rates low.

First, the heterogeneity in climate policies is likely to reduce. Most countries are expected to strengthen their climate policies over the coming decade in line with their nationally determined contributions to the Paris Agreement. Less policy divergence implies lower leakage rates, as the global playing field is more level. Second, leakage rates are not exogenous, but a function of carbon policy design. Policies can be designed to reduce leakage risks and mitigate competitiveness effects (Böhringer et al. 2012; Dröge et al. 2009; Fischer and Fox 2012; Martin et al. 2014; Pizer and Campbell 2021; Schmidt and Heitzig 2014). The leading countries on climate action are increasingly willing to put such measures in place. Interest in border carbon adjustment mechanisms, in particular, has moved from the academic into the policy debate.

It is not unlikely therefore, that carbon leakage will remain modest, as our evidence suggests it has been over the past twenty years.

Appendix

See Tables 8, 9, 10, 11.

Table 8 Correlation analysis

Explanatory variables	Outcome variables		
	$\ln(p)$	$\ln(c)$	$\ln(C/P)$
Recent laws	0.20***	0.22***	0.03
Older laws	0.27***	0.29***	0.02
Institutional quality	0.29***	0.33***	0.09***
$\ln(\text{GDP})$	0.52***	0.53***	-0.15***
HP filter	0.01	0.02	0.04
Import share	-0.25***	-0.22***	0.26***
Manufacturing share	0.38***	0.39***	-0.14***
Temperature	0.06**	0.06**	0.01

***, ** 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. The dependent variables are the natural log of per-\$ production and consumption emissions, denoted by $\ln(p)$ and $\ln(c)$, respectively, for emissions where $c = C/Y$ and $p = P/Y$, and the natural log of the ratio of consumption and production emissions ($\ln(C/P)$) for leakages. A balanced panel of 111 countries over 1996–2018 forms our estimating sample in all the estimations

Table 9 Stationarity tests

Variables	Chi ²	p-value
<i>Ln(p)</i>	269.409	0.016
<i>Ln(c)</i>	331.184	0.000
<i>Ln(C/P)</i>	456.348	0.000
Recent laws	321.413	0.000
Older laws	74.939	1.000
Institutional quality	225.514	0.422
Ln(GDP)	159.578	0.999
(Ln(GDP)) ²	160.550	0.999
HP filter	981.514	0.000
Import share	303.432	0.000
Manufacturing share	220.537	0.515
Temperature	1305.146	0.000
No. of countries	111	
No. of years	23	

Fisher’s 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 111 panels and 23 periods (years)

Table 10 Cointegration tests

Variables	<i>Ln(p)</i>	<i>Ln(c)</i>	<i>Ln(C/P)</i>
Modified Dickey–Fuller t	2.312**	− 2.728***	− 12.240***
Dickey–Fuller t	0.743	− 3.647***	− 10.057***
Augmented Dickey–Fuller t	2.301**	− 1.140	− 5.952***
Unadjusted modified Dickey–Fuller t	0.085	− 4.990***	− 15.106***
Unadjusted Dickey–Fuller t	− 1.109	− 4.910***	− 10.993***
No. of countries	111	111	111
No. of years	20	20	20

Kao test for cointegration is used. Null and alternative hypotheses, respectively, are: *Ho: No cointegration; Ha: All panels are cointegrated.* The dependent variables are the natural log of per-\$ production and consumption emissions, denoted by *Ln(p)* and *Ln(c)*, respectively, for emissions where $c = C/Y$ and $p = P/Y$, and the natural log of the ratio of consumption and production emissions (*Ln(C/P)*) for leakages. There are 111 panels and 20 periods (years) for the cointegration tests

Table 11 Test for overdispersion

Variables	(1) $\widehat{Ln(p)}$	(2) $\widehat{Ln(c)}$	(3) $\widehat{Ln(C/P)}$
$\frac{(\widehat{Ln(p)} - \widehat{Ln(p)})^2 - Ln(p)}{\widehat{Ln(p)}}$	-0.212*** (0.003)		
$\frac{(\widehat{Ln(c)} - \widehat{Ln(c)})^2 - Ln(c)}{\widehat{Ln(c)}}$		-0.210*** (0.018)	
$\frac{(\widehat{Ln(C/P)} - \widehat{Ln(C/P)})^2 - Ln(C/P)}{\widehat{Ln(C/P)}}$			-1.304 (1.803)
No. of Obs	2442	2442	2442
R ²	0.607	0.052	0.000

Standard errors are shown in parentheses. ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. This test follows the outline provided by Cameron and Trivedi (2010)

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