BRIEFING

Requested by the INTA committee

Economic assessment of Carbon Leakage and Carbon Border Adjustment

Policy Department for External Relations
Directorate General for External Policies of the Union
PE 603.501 - April 2020

EN

DIRECTORATE-GENERAL FOR EXTERNAL POLICIES
POLICY DEPARTMENT

BRIEFING

Economic assessment of Carbon Leakage and Carbon Border Adjustment

EXECUTIVE SUMMARY

The European Union is the world's largest importer of virtual CO2-emissions: its net imports of goods and services contain more than 700 million tons of CO2 emitted outside of the EU's territory. This is more than 20 % of the EU's own territorial CO2 emissions. Therefore, shifting carbon pricing away from pricing the EU's territorial emissions to pricing the EU's CO2-footprint (by means of carbon border adjustment) enhances the reach of European climate policy activities and increases their effectiveness for promoting global abatement activities.

The above result relies only on the EU being a net importer of CO2 emissions embodied in international trade. It does not rely on the answer to the question, whether stronger unilateral CO2 mitigation efforts in the EU cause the imports of embodied carbon to increase (direct carbon leakage).

Direct carbon leakage refers to the possibility that stringent unilateral CO2 policies in the EU, e.g. in the form of high carbon prices or regulatory measures, might lead to an increase in the carbon imports embodied in trade of goods and services: as European firms' relative production costs are driven up relative to firms in non-committed foreign countries, domestic production is replaced by imports and domestic emissions are replaced by foreign ones. This compromises the effectiveness of the EU's climate policies and endangers jobs and value added in exposed sectors.

Ex post evaluations of existing carbon policies arrive at mixed conclusions. On the one hand, emission pricing in the EU ETS, so far, is mostly not found to cause direct carbon leakage. On the other hand, studies based on a broader focus of climate policies (not just carbon prices) suggest that measures, e.g., in the context of the Kyoto Protocol, have indeed led to carbon leakage. In countries that have committed to emission targets, imports of goods have gone up by about 5 % and the carbon-intensity of imports has gone up by 8 %.

Ex-ante predictions by simulation models indicate that direct leakage is indeed likely. Its size depends on the difference between the EU's carbon prices and those of its trading partners. On average, studies indicate that about 15 % of domestic emission savings are offset by additional foreign emissions. However, the range of estimates is very large. In most studies, indirect carbon leakage that operates through global markets for fossil fuels, however, is quantitatively more important than direct carbon leakage operating through international markets for goods and services.

Ex-ante models show that carbon border adjustment can reduce carbon leakage. In complete setups, it can fully eliminate direct leakage. It does little to reduce leakage through energy markets, or to incentivise countries to engage into more ambitious climate policies. Results depend crucially on the design of the mechanism. Moreover, simulations also show that the adjustment burden is shifted to non-abating countries, many of which are poor and underdeveloped.

The note concludes that carbon leakage is an empirically relevant concern. Carbon border adjustments (CBAs) can lower carbon leakage occurring through goods markets. CBAs need to be treated very carefully because they might provoke retaliation by non-committed countries and because they may shift the burden of adjustment to poor countries. In the context of the EU ETS, one promising strategy could be to grant free allocations of emission permits to leakage-prone industries but combine this with a consumption tax, applied to domestic and foreign goods produced by those exempted industries.

EP/EXPO/INTA/FWC/2019-01/Lot5/1/C/02
April 2020 - PE 603.501

EN

This briefing was requested by the European Parliament's Committee on International Trade.

English-language manuscript was completed on 14 April 2020.

Printed in Belgium.

Authors: Prof. Gabriel Felbermayr and Prof. Sonja Peterson, Kiel Institute for the World Economy (IfW Kiel).

Official Responsible: Mario DAMEN

Editorial Assistant: Jan MUYLDERMANS

Feedback is welcome. Please write to: mario.damen@europarl.europa.eu or wolfgang.igler@europarl.europa.eu.

To obtain copies, please send a request to: poldep-expo@europarl.europa.eu

This paper will be published on the European Parliament's online database, 'Think tank'.

ISBN: 978-92-846-6752-9 (pdf)
doi: 10.2861/577601 (pdf)
Catalogue number: QA-02-20-394-EN-N (pdf)

ISBN: 978-92-846-6753-6 (paper)
doi: 10.2861/02958 (paper)
Catalogue number: QA-02-20-394-EN-C (paper)

Table of contents

1 The fundamental problem: Policy fragmentation

'Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.' (Stern, 2007). The market failure refers to the fact that decentralised mitigation efforts do not suffice to achieve the necessary amount of reductions in global CO2-emissions. The climate is a global public good; since mitigation efforts are costly, countries have strong incentives to free-ride on the efforts of other. Whether emissions are reduced abroad or at home makes no difference for the local consequences of climate change. Therefore, it is immensely challenging to commit all countries to emission mitigation policies (Nordhaus, 2015).

Nonetheless, 197 countries are parties to the Paris Climate Agreement, 187 have ratified it. By doing so, they acknowledge that 'climate change is a common concern of humankind', and they recognise that there is a 'need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge'. The parties have agreed to undertake 'ambitions efforts' 'as nationally determined contributions to the global response to climate change' (Art. 3). They have also reaffirmed the 'principle of common but differentiated responsibilities'. Moreover, obligations in the Paris Agreement are legally non-binding, and countries may not comply with their obligations because there are no sanctions for noncompliance (Kortum and Weisbach, 2016). Indeed, the free-riding problem in combatting global climate change is strong (Nordhaus, 2015). For this reason, the world is set for unilateral climate policies at the national level that are likely to be highly heterogeneous regarding their level of ambition as measured by the percentage reductions of territorial emissions. Countries not only differ with respect to their targets, they also differ with respect to the instruments.

The core problem of global climate mitigation policies is that the world has not adopted a common price for carbon emissions or a binding emission cap. For this reason, Nobel Prize winner William Nordhaus (2015) has famously called to focus efforts on creating a large coalition – a Climate Club – of countries willing to engage into mitigation policies. Based on economic theory and empirical modeling, he argues that without sanctions against non-participants there are no stable coalitions other than those with minimal abatement. By contrast, a regime with small trade penalties on non-participants, a Climate Club, can induce a large stable coalition with high levels of abatement.

Policy-makers have to deal with the fact that there is no such Climate Club and that only a subset of regions, the European Union being one of them, is willing to adopt sufficiently ambitions climate policies. The problem with unilateral, heterogeneous climate policies is that they reduce the effectiveness and efficiency of unilateral carbon policies such as CO2-prices. Moreover, by giving rise to competitiveness concerns, asymmetries undermine more ambitious national climate policy initiatives. Global climate warming can be effectively addressed by a global policy approach only.

The fragmented global carbon policy landscape lies at the core of the leakage problem. If all relevant countries of the world where to engage into comparable carbon mitigation policies such as carbon pricing through a global cap-and-trade system, no leakage problem would arise.

2 Types of carbon leakage

Carbon leakage is defined as the additional CO2 emissions of non-mitigating countries (i.e. subjected to a weak reference policy) compared to the CO2 abatement achieved by pioneering regions (i.e. pursuing additional policy ambition such as the European Union). Carbon leakage is an important aspect of the globally fragmented CO2-policy landscape as it has implications on GDP growth, trade, employment, emissions and business decisions.

Carbon leakage can take place through two main mechanisms or channels that are activated by policy-induced changes in relative prices (Arroyo-Curràs, 2015; Böhringer et al., 2017):

(i) changes of international trade in goods and services that embody carbon emissions generated during the production process, also known as direct leakage or the product market or competitiveness channel; this channel may operate or be magnified by international mobility of firms, i.e. by a capital market channel;

(ii) changes in the patterns of international fossil fuel trade, which has been called indirect leakage or the energy markets channel.

Channel (i) is theoretically explained by the pollution haven or factor endowment hypotheses. The energy markets channel (ii) results from reduced demand for fossil fuels due to unilateral action in emission abating regions, which depresses global energy prices and induces larger demand and consumption in non-abating regions. Sometimes the literature also discusses a spill-over channel which refers to the possibility that carbon policies of committed regions lead to technological progress that spills over to non-committed regions and may help lower emissions there. Notice that carbon leakage can be positive (most likely for channels (i) and (ii)) or negative (i.e., when carbon unilateral policies facilitate emission savings in non-abiding countries). In the following, attention is focused on channel (i) because of its interaction between trade and climate policy.

3 Carbon footprints, territorial emissions and carbon embodied in imports in the data

The importance of international trade is best illustrated by comparing the European Union's territorial CO2-emissions with its CO2-footprint[1]. The difference between the two measures is made up by international trade.

3.1 Territorial emissions and footprints

Territorial emissions are defined as the sum of all CO2-emissions that occur in a specific year on the territory of the Union. They capture emissions generated by producing goods and services within the borders of the EU. Official international CO2-accounting is based on this concept. Most concepts of CO2-pricing use territorial emissions as the basis on which levies are applied[2]. Figure 1 shows that the EU's CO2 emissions have fallen over time. From 1990 to 2017, they have decreased by 21 % (and by 23 % from 1990 to 2018[3].

The figure also shows the EU's carbon footprint. This measures the carbon content of all goods and services absorbed (i.e., consumed or invested by private or public agents) in the EU, regardless whether they have been produced on the territory of the EU or abroad. The estimation of the carbon footprint requires tracking the carbon content of goods and services produced abroad and absorbed in the EU, the carbon content of goods and services produced in the EU for domestic absorption, and the carbon content of goods and services produced in the EU for foreign absorption. The measure requires knowledge of foreign direct and indirect emissions associated to the production of goods and services. Since intermediate inputs are often imported from abroad, and those inputs may contain further inputs from yet other countries, the estimation of the CO2-footprint makes use of a world input-output table for each year in order to capture

---

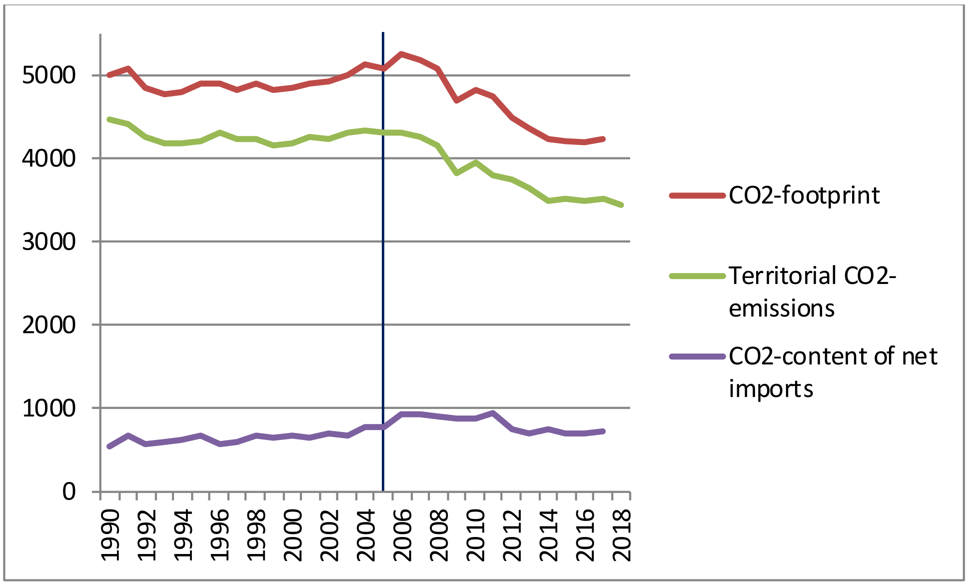
[1] In the following the term CO2 generically refers to greenhouse gases in CO2-equivalents.

[2] The following discussion does not hinge on whether carbon pricing is implemented via CO2-taxes or emission trading.

[3] Note that due to different methodologies, data published by the Global Carbon Project (2019) differs slightly from official EU data (as reported, e.g., by Eurostat or the European Environment Agency); see Friedlingstein et al. (2019)

global production networks[4]. The CO2-footprint is often also referred to as CO2-consumption (as embodied in goods and services).

Figure 1 Estimates of European Union CO2-emissions, CO2-footprint and CO2-imports, in million tons of CO2 per year



Source: Global Carbon Project (2019), own calculations and illustration. Note: emission data differ from official EU data due to different treatment of CO and CO4 emissions. The EU is defined over 28 members (as of 2019). Vertical line indicates the start of the EU Emission Trading System (ETS) in 2005.

Figure 1 shows that the CO2-footprint of the EU is higher than territorial emissions, implying that the EU is a net importer of CO2. In other words, imports into the EU are related to higher CO2-emissions abroad than exports from the EU to foreign countries. The footprint has fallen by 15 % from 1990 to 2017. Thus, the reduction in the carbon footprint has been less pronounced (by 6 percentage points).

3.2 Carbon trade

Figure 1 plots net imports of CO2[5]. Net imports of CO2 are the difference between the footprint and the territorial emissions. They have increased by 33 % between 1990 and 2017. The fact that, in 2017, through trade of goods and services, the EU has been importing more CO2 than it has been exporting, is despite it being a net exporter of goods and services of about EUR 167 billion. The CO2-content embodied by imports into the EU must be much larger than the CO2-content of domestically produced goods[6]. In 2005, when the EU's ETS came into force, the data suggest a small uptick of net carbon imports, which would be consistent with the idea that unilateral climate policy leads to carbon leakage.

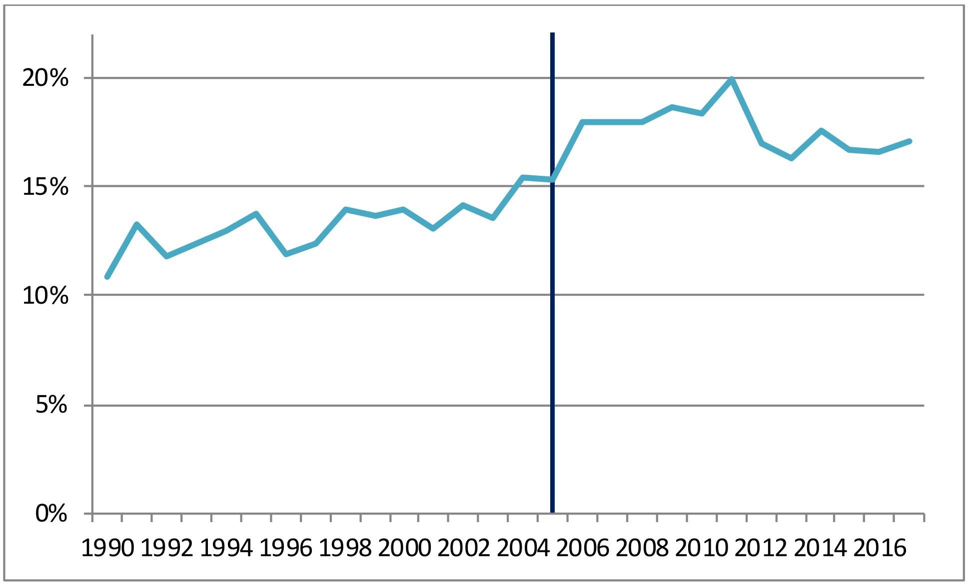
---

[4] See Peters et al. (2011) or Aichele and Felbermayr (2012) for details on the procedure.

[5] Peters and Hertwech (2008) refer to net carbon imports as a weak version of carbon leakage. We prefer reserving the term 'leakage' to situations, where delocalisation of carbon emissions is explicitly triggered by differential climate policies.

[6] Eurostat calculations of the EU's carbon footprint make the assumption that foreign production is exactly as carbon-intensive as EU production. Empirically, this is a very misleading assumption. World Bank data reveals that the CO2-intensity of GDP (measured in kg territorial CO2-emissions per 2010 US$ of GDP) was 0.18 in the European Union (ranging between 0.08 in Sweden and 0.86 in Estonia), but 0.32 in the US or 1.24 in China, 1.69 in Ukraine, and 0.49 on average at the global level. Hence, the Eurostat methodology results in very small difference between the footprint and territorial emissions. Moreover, as the EU has become a net exporter of goods and services since 2008, implied carbon imports have fallen and turned negative (i.e., the EU is a net carbon exporter); see https://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics_-_carbon_footprints#Carbon_dioxide_emissions_associated_with_EU_consumption.

Figure 2 CO2 embodied in net imports as a share of EU carbon footprint, %



Source: Global Carbon Project (2019), own calculations and illustration. Vertical line indicates the start of the EU Emission Trading System (ETS) in 2005.

Figure 2 plots the EU's CO2-emissions embodied in net imports as a percentage share of the EU's CO2-footprint and finds that it has been increasing from 11 to 17 % from 1990 to 2017. The recent reduction is due to lower CO2-intensities of production in main sources of imports, most notably in China.

In 2017, with 728 million tons, the EU is the world's largest net importer of CO2-emissions. The US, another major importer, accounts for 416 million tons. This is because the US has a higher average CO2-intensity of production so that its territorial emissions and its footprint coincide more closely. China, in turn, is the largest net exporter of CO2: its net exports amount to 1 290 million tons. China has reduced its net exports from 1 503 million tons in 2014.

Of course, at the global level, territorial emissions and the footprint coincide. But at the sub-global level, implicit trade in CO2 is quantitatively important and the EU plays a major role. Table 1 shows that the EU's territorial emissions accounted for about 9.8 % of global emissions in 2007, the CO2-footprint accounted for 11.8 % and net imports of CO2 for 2.0 %.

3.3 Implications for carbon border adjustment

As a consequence, it EU carbon pricing (through the ETS and national regimes) is applied to the carbon footprint rather than to territorial emissions, the share of global emissions addressed by EU policies grows from 9.8 % to 11.8 %. A border adjustment mechanism can, partly or completely, achieve this by focusing on pricing CO2 emission associated to EU absorption (consumption and investment) activities rather than on emissions related to EU production. A mechanism that subjects the carbon content of imported goods and services to EU carbon pricing and exempts the carbon content of exported goods and services would achieve this objective.

Naturally, by moving a larger share of global emissions under the EU's carbon pricing regime, and assuming that the EU has more stringent carbon policies than the average trade partner the impact of the EU's mitigation policies on global emissions increases. (7) This result is entirely independent from the question

---

[7] This assumption is validated by Botta, E. and T. Kozluk (2014) and the updated results published in the OECD's Environmental Policy Stringency Index on https://stats.oecd.org/Index.aspx?DataSetCode=EPS.

whether more stringent climate policies (e.g., higher carbon prices) would further increase net imports of embodied CO2.

Table 1 EU CO2 emissions: territorial measure versus footprint, 2017

	CO2-footprint	Territorial CO2-emissions	CO2-content of net imports
in million tons	4 246	3 518	728
in % of global emissions	11.8 %	9.8 %	2.0 %

Source: Global Carbon Project (2019), own calculations and illustration.

4 Does carbon pricing cause leakage?

To what extent do unilateral climate policies drive up net imports of CO2, thereby crowding out domestic production? The evidence presented in Figure 1 and Figure 2 cannot answer this question. Too many other factors determine whether countries are net importers or exporters of carbon-intensive goods. For example, countries running large trade deficits, ceteris paribus, should also be net importers of carbon. Countries specialised in the production of CO2-intensive manufacturing activities naturally are net exporters of carbon while countries specialised in services are net importers. While unilateral climate policies may of course influence trade balances and specialisation patterns, they are by no means their only drivers. Moreover, there are issues of reverse causation: countries being net exporters of carbon – for whatever reason that may be – have little interest in adopting aggressive carbon pricing policies as this reduces their comparative advantage in those industries. So, there may be many reasons for a correlation between carbon imports and carbon pricing, but the latter may not cause the former. To address this issue, one has to engage into more formal economic modeling. There are two broad research strategies:

(a) Analyses of carbon leakage and of carbon border adjustment policies in simulation models of the world economy, so called Computable General Equilibrium (CGE) models. These models typically answer how specific future carbon policies affect outcomes: trade flows, carbon emissions nationally and globally, and welfare. In most cases, CGE analysis engages in an ex ante analysis.

(b) Econometric modeling of existing carbon policies engage in ex post analyses. That is, they ask how policies such as the European Emission Trading System or international agreements such as the Kyoto Protocol have affected carbon leakage. Those studies focus on trade flows and carbon emissions embodied in trade flows, as well as on aggregate emissions.

4.1 Factors driving direct carbon leakage

The mechanism that receives most attention is the competitiveness channel discussed in section 2 (direct leakage) and operates through international markets for goods and services. A unilateral carbon price in one region of the world (e.g., in the EU) would increase the production costs of goods whose production involves emissions of CO2 but not in countries or regions that do not commit to carbon pricing or other equivalent carbon policies. Hence, the relative price of EU goods would increase relative to foreign goods. Users – consumers or investors – of those goods would substitute towards goods produced in foreign countries and away from domestic production. Firms would increase the capacity of production abroad and reduce it at home. The output of carbon-intensive industries at home falls while that of non-intensive sectors expands; CO2-emissions fall. Abroad, the opposite happens: output of carbon-intensive industries goes up while that of non-intensive sectors falls; CO2-emissions increase. The leakage rate measures the share of domestic emission savings that is offset by foreign emission increases. That share can be larger than 100 % when foreign production is particularly CO2-intensive. In any case, leakage reduces the effectiveness of domestic carbon policy because the domestic effort does not reduce global carbon emissions one-to-one.

This mechanism works regardless of how CO2-pricing is implemented, either via a unilateral cap-and-trade system or via unilateral CO2-taxes. If both regions have the same CO2-prices, relative cost competitiveness does not change. Unilateral carbon pricing leads to sectoral adjustments that go beyond those that would arise if all countries had the same CO2-prices and/or a common cap on carbon emissions. The literature finds that direct leakage is larger,

(i) the smaller the coalition of countries committed to carbon policies is relative to the world and the larger differences in CO2-prices between regions or countries are;

(ii) the more carbon-intensive the production of goods or services is (based on direct and indirect (through intermediate inputs) CO2-emissions;

(iii) the lower trade costs – tariffs and other frictions such as regulatory barriers or transportation costs – are;

(iv) the more easily substitutable foreign and domestic outputs are, that is, the stronger (the more elastic) demand reacts to price changes;

(v) the more competitive goods markets are so that firms cannot easily pass-through higher costs to users at unchanged quantities.

Industries differ with respect to these criteria; hence, the likelihood of direct leakage differs across industries. To make the risk for carbon leakage more operational, the literature classifies industries according to their CO2-intensity, their elasticity of demand, and the larger their trade exposure. The larger the share of fossil fuels in the cost base of firms, the more price competitiveness suffers as a consequence of CO2-prices. The higher the elasticity of demand, the more strongly demand shrinks as prices (driven by higher costs) go up. And the larger export shares are, the bigger the threat to domestic value added and employment.

4.2 Core findings from simulation studies

There is a relatively substantial literature presenting studies that simulate the effectiveness of unilateral climate policies in models featuring international trade, and, in some cases, international mobility of capital and firms. One can distinguish two types of approaches which matters for the findings:

(i) Computable General Equilibrium (CGE) modeling analyses, with many sectors and countries, which take an economy-wide perspective and explicitly model how single industries are embedded in national and international value chains, taking impacts of macroeconomic aggregates into account, and

(ii) Partial equilibrium models which focus on single industries, often in single countries, taking macroeconomic aggregates as given.

Both of these approaches have advantages and disadvantages; ideally they should be used in concert. CGE models tend to forecast lower leakage rates because they provide results for a blend of sectors that are more and less heavily exposed to leakage, while partial equilibrium models tend to focus on individual sectors expected to be particularly vulnerable to carbon leakage.

Results from CGE models

Leakage rates are in particular quantified with the help of CGE models in ex-ante studies of for hypothetical climate policy scenarios such as meeting the Paris targets. The early CGE-literature, e.g., Babiker (2005) estimates leakage rates as high as 130 percent, meaning that domestic emission savings are more than offset by additional emissions abroad. These results have been dismissed by newer research and hold only under special circumstances such as wide-spread increasing returns to scale production technologies and oligopolistic market structures.

Branger and Quirion (2013) have produced a very useful meta-analysis of the large and sprawling CGE literature on carbon leakage and carbon border adjustments. They analyse 25 studies with a total of 310 estimates of carbon leakage ratios. The typical range of carbon leakage estimates is from 5 % to 25 % (mean 14 %). Similarly, Böhringer et al. (2018) summarise their survey of the existing CGE literature by saying 'Average leakage rates in CGE studies of comparable climate policy regulations range between 10 and 30 percent.' These estimates do not include carbon border carbon adjustment (CBA) measures. With those in place, leakage is reduced to – 5 % to 15 % (mean 6 %). Models differ with respect to structural assumptions and parametrisations; also the specific implementation of the CBAs differ, but the averages do signal where the economic analysis are pointing to.

Branger and Quirion (2013) summarise the general findings of the literature very well. The study also shows that leakage ratio falls with the size of the coalition of countries that undertake ambitions carbon policies. Among different CBA options, the extension of CBAs to all sectors and the inclusion of export rebates are the most efficient features in the meta-regression model to reduce the leakage ratio. All other parameters being constant, CBAs reduce leakage ratio by 6 percentage points.

Results from industry-level studies

Concerning studies based on partial equilibrium models, Partnership for Market Readiness (2015) presents a very complete overview. The many existing studies focus on particular countries and sectors, where the industries that are most vulnerable to carbon leakage have received most attention. These include the cement, clinker, steel, aluminum, oil refining and electricity sectors.

The partial equilibrium models typically generate large leakage rates, often up to 100 %. These rates are substantially larger than those obtained in the CGE literature. The reason is that the partial equilibrium models focus on very special sectors that feature a high degree of vulnerability but that do not receive a high weight in country-wide assessments. It is perfectly possible for single industries to displace leakage rates of 100 % while the CGE analysis, focusing on the same carbon policies, may find leakage rates that are an order of magnitude smaller. Moreover, the CGE analysis and the partial equilibrium models differ with respect to crucial assumptions. The latter mostly do not allow for products to be differentiated with respect to their origin (European steel is deemed identical from a user perspective than imported steel) and assumes oligopolistic behavior of firms. These features drive up leakage. CGE models typically assume that users differentiate between origins of products and feature perfectly or monopolistically competitive product markets; these characteristics lower leakage.

A shortcoming of both model types is that technological innovations induced by climate policy are typically not captured. This means that those frameworks may overestimate the amount of leakage and the absolute value of welfare effects; see Gerlagh and Kuik (2014). Thus, the spill-over channel alluded to in Section 2 is not covered.

4.3 Econometric analysis of trade flows and carbon leakage

The carbon leakage problem is a special case of the 'pollution heavens' problem. For more than 40 years, there has been econometric research on the question whether countries with relatively weak environmental regulation attract pollution intensive production. Levinson (2008) provides an extensive survey of the literature and its findings. He argues that early empirical work on the pollution haven hypothesis had some methodological shortcomings[8]. Most of the studies found small insignificant effects of environmental regulations, a few found counter-intuitive positive effects, and none found robust significant support for the pollution haven hypothesis. This early literature is summarised in Jaffe et al. (1995, p. 157): 'Overall, there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness.'

In contrast to the earlier cross-section studies, newer work based on more advanced methodologies has tended to find statistically significant, reasonably sized evidence of pollution havens[9]. It is catalogued in detail by Brunnermeier and Levinson (2004), and summarised in Copeland and Taylor (2004, p. 48), who write that 'after controlling for other factors affecting trade and investment flows, more stringent environmental policy acts as a deterrent to dirty-good production'. Larger and more significant trade flow effects are found for less pollution-intensive industries, see Ederington et al. (2005), Levinson and Taylor (2008), and Levinson (2010). An explanation that has been put forward is that pollution-intensive industries tend to be relatively immobile, while less pollution-intensive industries tend to be more labor-intensive and geographically 'footloose'.

The empirical literature on carbon leakage is possibly undergoing a similar graduation. Both the older and the newer ex post evaluation studies suffer from three additional problems which can be addressed only in general equilibrium simulation models. First, the studies rely on linear (logarithmic) approximations; predictions, e.g., about the effects of policies that are much more stringent than the ones evaluated in historical data, are therefore problematic. In particular, in the presence of fixed costs of relocation, the incentives for production relocations increase over proportionately with the stringency of the policy measure. Second, the studies compare sectors, regions, or industrial installations that are covered by measures with differing intensity. Effects of measures (i.e., more stringent reporting requirements) that affect all units of observation regardless of how and whether they are specifically affected by a measure cannot be identified. Third, the studies raise questions about external validity: can results obtained for certain sectors, regions, and time periods be credibly used to inform current policy making?

Contrary to modelling studies that can assess hypothetical climate policy scenarios with very stringent unilateral climate policies empirical studies can only assess carbon leakage of existing policy sets. Leakage rates that are found in these studies are significantly lower than those reported above which can to some degree be attributed to the analysed scenarios.

Evidence on the European Emission Trading System

Since 2005, the ETS is a cap-and-trade system that covers CO2 emissions from manufacturing, electricity production and aviation (for flights within the EU). It sets a limit to territorial emissions and this limit gradually falls over time (by 2.2 % after 2020). In early years, emission allowances were mostly distributed freely; in phase 3 (2013-2020) of the ETS, by default, they are auctioned off. Only installations in sectors deemed exposed to carbon leakage receive free allowances. Allowances are traded on a market, and the fact that they are limited generates a positive price.

According to ETS Directive Article 10a, a sector is defined as 'exposed' to carbon leakage if additional costs caused by the ETS, as a share of gross value added, is at least 5 % and the sector's trade intensity with non-EU countries (imports and exports) is above 10 %. Alternatively, a sector is 'exposed' if additional costs are at least 30 % or the non-EU trade intensity is above 30 %. Installations in exposed sectors are eligible to receive free allocation of permits, which is determined by multiplying the production quantity of a product by a benchmark carbon coefficient for that product. Benchmarks are based on the performance of the most

---

[8] The studies used cross sections of data and made no attempt to control for unobserved heterogeneity or simultaneity.

[9] This included the use of panels of data and fixed effects models to control for unobserved heterogeneity, and instrumental variables to control for simultaneity.

efficient installations, so only the most efficient installations receive free allowances to cover their entire needs. For installations in non-exposed sectors, free allocations are gradually phased out by 2030. Before phase 3 of the ETS similar but slightly different rules applied; in phase 4, another modification of the rules will kick in but the overall logic is maintained.

The allocation of free allowances reduces the danger of carbon leakage by reducing average costs of carbon intensive producers in the EU. Because only the most efficient producers receive full allowances, incentives to reduce emissions are maintained despite the existence of free allocations. During long periods of the existence of the ETS, prices for EU emission allowances have been very low. This has several reasons; see Grosjean et al. (2016). One important driving factor, of course, was the recession of 2009. However, national policies aimed at promoting the production of renewable energy have also led to low prices as they have reduced demand for EU emission allowances. Thus, during most of the EU ETS' history, price signals have been relatively low.

Thus, it is probably not overly surprising that ex post modeling analyses of the EU ETS have generally found little evidence of leakage (Partnership for Market Readiness, 2015). The results are consistent, however, with the analyses of the impact of other local environmental policies that have been observed for a longer time in a wider range of countries. Ever since the 1970s they were also feared for causing the potential migration of industry to 'pollution heavens' abroad, which has not materialised on a significant scale. Environmental policies have even been found to induce innovation that offsets part of the cost of compliance with the environmental policy. This is not surprising for economists who have long observed that firms do not compete on costs only, but on the overall efficiency of converting various inputs (including knowledge) into high-value products and services. Cost competition is more important to sectors offering homogenous products and commodities.

Indeed, Sato and Dechezlepretre (2015) find that emission cost imposed by the EU ETS are below 0.65 % of material cost for 95 percent of European manufacturing sectors. Thus, the additional cost introduced by European emissions policy is comparatively small. Sato and Dechezlepretre add that firms relocating production to a foreign region must pay fixed relocation costs. Relocation also has opportunity costs in the home market, such as a weaker market position and less influence in bargaining with policy makers. Moreover, emission policies often combine costs and subsidies. For example, European manufacturing firms received large amounts of free emissions allowances ('free allocation'), which may be sufficient to counter the leakage risk. The data of the authors reveal that most sectors received a net subsidy from emissions trading, once free allocation is taken into account. Finally, the business literature predicts an inverse effect of environmental regulation (Porter hypothesis): the negative competitiveness effects of unilateral environmental policy may be offset by successful incentives to innovate in lower-carbon products, spurring a broader productivity increase for firms affected by environmental policies. Innovation may be incentivised through the emission price signal or by providing explicit R&D subsidies in parallel.

Very recently, Chevallier and Quirion (2017) conduct an econometric analysis of carbon leakage resulting from the EU Emission Trading Scheme (ETS) on the cement and steel sectors. They find no evidence that the EU ETS has had any effect on net imports in these energy-intensive sectors. Generally, newer papers confirm the general finding in Partnership for Market Readiness (2015) that there is no evidence supporting strong leakage effects due to the EU ETS.

Sato and Dechezlepretre admit that 'it is difficult to know for certain what explains the ex post modeling result of carbon leakage in Europe so far. While it could mean that the risk of leakage is negligible for the reasons described above, it could also be explained by the technical difficulties in identifying impacts over a relatively short period of time; or because carbon prices have been modest; or because of the efficacy of leakage-prevention mechanisms that have been part of policy design from the outset.'

Nägele and Zaklan (2017) use a so called gravity equation for the carbon dioxide content of trade, which accounts for intermediate inputs, both domestic and imported to study how trade flows and their carbon content of trade is affected by the EU ETS. Their analysis suggests that carbon leakage did not occur due to the EU ETS per se but that there was carbon leakage due to other climate policy measures that committed countries implemented, most likely, regulations.

Evidence on climate policy on trade flows and emissions

The literature cited above suffers from a number of problems. It draws inference on past experience, and it focuses exclusively on carbon pricing. However, in the past, over long periods, CO2-prices in Europe have been very low. It would be surprising if they triggered strong responses. In contrast, many EU countries and the EU implemented ambitious regulatory measures to curb CO2-emissions (e.g., EU wide fleet emission targets for cars), installed subsidies for clean energy production and financed those using levies on electricity users (e.g., Germany's Renewable Energy Sources Act), and so on. Many of these measures did impose additional costs on producers, sometimes explicitly, more often implicitly. Therefore, to capture the effects of climate policies on trade flows, one needs to cast a wider net.

There is an empirical literature that does this. It compares outcomes in countries that have made commitments under the Kyoto Protocol and hence have had to implement appropriate policies with countries that did not underwrite such commitments.

Grunewald and Martinez-Zarzoso (2016) show empirically in a large panel of countries that commitments in the context of the Kyoto Protocol have indeed led to lower territorial CO2 emissions. This is in line with Aichele and Felbermayr (2012). However, those authors analyse not only territorial emissions but also the carbon content of domestic absorption (consumption and investment). They use a large panel of countries and a so called instrumental variables estimator to identify the causal effect of ratification of binding Kyoto commitments on the carbon footprint and territorial emissions. They show that Kyoto commitment has reduced domestic emissions in committed countries by about 7 % but has not lowered carbon footprints. Instead, the share of imported over domestic emissions went up by about 14 percentage points. These results suggest that the Kyoto Protocol may had the intended effects on domestic emissions but had no effect on world-wide emissions as footprints have not fallen. Such evidence is consistent with carbon leakage.

The mentioned papers do not explore the channels through which Kyoto commitments have lowered territorial emissions. In particular, crucial for the leakage debate, those papers do not make the role of international trade explicit. Finally, there is one paper that asks how the collection of policies have, on average, affected the carbon content of trade between countries with binding commitments from the Kyoto Protocol and those without. Aichele and Felbermayr (2015) use a so called gravity equation for the carbon dioxide content of trade, which accounts for intermediate inputs, both domestic and imported. They use a large panel database of the carbon content of sectoral bilateral trade flows and deal with the non-random selection of countries into the Kyoto Protocol. They find that binding commitments under Kyoto have increased committed countries' embodied carbon imports from non-committed countries by around 8 % and the emission intensity of their imports by about 3 %. The conclusion, therefore, is that policies triggered by the Kyoto Protocol have indeed led to leakage.

The policy that has been analysed most extensively is the European Emission Trading System to which we thus denote an extra paragraph.

5 Addressing carbon leakage

5.1 A 'complete' carbon border adjustment (CBA) regime

In a world where only a subset of countries engage in carbon pricing, direct carbon leakage can be fully neutralised by a regime that subjects the carbon content of imports of goods and services to the same carbon price as applied to the carbon content of domestic production, while at the same time rebating paid carbon taxes or allowances to exporters according to the carbon content of their goods. Such a regime effectively shifts the burden of carbon pricing away from domestic production to domestic absorption (consumption and investment). As consumers are not geographically mobile, they cannot escape the carbon price. Production, in contrast, can shift from the EU to foreign places. With identical carbon prices applied to the CO2-content of all goods and services regardless of their place of origin, carbon leakage disappears. In such a situation, the EU carbon policy does not induce any substitution effects and, thus, minimises inefficient trade diversion or evasion effects. Compared to a situation without any carbon pricing in any country, this regime has no first order effects on relative prices as domestic and imported goods and services are treated alike. Compared to an initial situation where carbon prices apply to domestic production only, switching to the described 'complete' regime hurts trade partners because demand for their goods in the EU fall; this lowers their exports to the EU and their terms-of-trade fall[10]. However, the regime corrects a deterioration of EU terms-of-trade that occurred when the ETS was introduced in the first place. The 'complete' regime is similar to a value added tax, which subjects any good, regardless of origin, to the same tax; it is different to a carbon tariff, which, by definition, discriminates against foreign producers.

Böhringer et al. (2018) study the effects of such a carbon tariff. They look at the effects of taxing the carbon content of imports in a CGE model. They refer to this as 'embodied carbon tariffs', since a tax is applied to the carbon content of imports which is not (necessarily) also applied domestically. They show that such a policy shifts the burden of adjustment to foreign countries, mostly by deteriorating their terms-of-trade: as foreign goods become more expensive, demand for them falls, and foreign producers typically find it optimal to adjust their prices downwards. Such a policy imposes incentives on foreign producers to reduce emissions as this lowers their effective tax burden. It also leads to trade diversion: carbon intensive goods are rerouted to other markets. As with other beggar-thy-neighbour policies[11], it can result in reduced global welfare. Böhringer et al conclude that such tariffs can represent a tempting policy option for countries that seek to reduce their domestic compliance costs under the pretext of eliminating carbon leakage from their unilateral climate policy initiatives. However, the tariff could be used as a means to sanction countries that are not willing to join the Climate Club as suggested by Nordhaus (2015).

Moreover, there are important implementation issues of the complete CBA. The carbon content of foreign goods would have to be identified which is probably bureaucratic; with return to this important concern below. Foreign countries may feel treated unfairly and engage into retaliation. Finally, there may be issues regarding the compatibility of the regime with respect to WTO rules.

---

[10] Terms of trade describe the relationship between the prices obtained (on average) for export goods relative to import goods. Higher terms of trade improve the purchasing power of a country and, hence, welfare.

[11] 'Beggar-thy-neighbour' policies are unilateral strategies that aim at transferring income or economic rents from foreign countries to the home country, e.g., by manipulating the terms of trade. The term goes back to Adam Smith (1776).

5.2 Smart hedging against carbon leakage

Recently, Böhringer et al. (2019) have proposed a border adjustment scheme which can, at least in theory, fully replicate the complete regime described above, while offering advantages regarding the legal, diplomatic, and technical feasibility.

As described above, the existing EU ETS already contains provisions to mitigate carbon leakage. This happens with the help of output-based allocation (OBA) of allowances to exposed industries: in proportion to their actual emissions companies in such industries get all or part of the needed allowances for free; incentives are maintained by indexing OBAs for all firms to the most efficient establishment. This strategy lowers average costs of European producers and, thus, improves their international competitiveness relative to a situation without free allowances. However, it has the disadvantage that it leaves certain carbon-intensive goods entirely exempted from carbon pricing so that their domestic (and global) use remains too high. Böhringer et al. (2019) show that in a situation with an ETS combined with OBA, it is optimal to impose a consumption tax on the goods that are entitled to OBA, where the tax is equivalent in value to the OBA-rate. Then, using a multi-region, multi-sector computable general equilibrium (CGE) model calibrated to empirical data, they quantify the welfare gains for the EU to impose such a consumption tax on top of its existing ETS with OBA. They run simulations to account for uncertain leakage exposure of goods entitled to OBA. The consumption tax increases welfare whether the goods are highly exposed to leakage or not. Thus, policy makers in regions with OBA can only gain by introducing the consumption tax. Because the OBA-cum-tax system is already up and working, without major concerns by trade partners or the WTO, it may be preferable to the complete CBA regime described in 5.1.

Analytically, it is possible to show that the OBA cum tax system can be designed such that it completely replicates the 'complete' CBA. This would mean to calibrate the free allowances to industries and the tax in a way that gives exporters the same effective rebate as exempting their exports from a universal carbon pricing system without OBA. Doing this requires the same information as in the 'complete' CBA. If carbon contents of imports and exports are not known exactly, and the EU has to apply some benchmark or average to calculate fees and rebates, the 'complete' CBA can easily become the subject of litigation because firms may complain about discriminatory treatment. The OBA cum tax system may be less vulnerable to this problem, for example, if the consumption tax does not differentiate between different origins of the goods in question. Nonetheless, it goes some way into reducing carbon leakage and extending the global reach of EU climate policies.

5.3 Positive and negative economic effects of CBA

A well-designed CBA mechanism decreases leakage, and can therefore be expected to raise welfare in the countries unilaterally undertaking climate policy. But it is no substitute for universal global carbon pricing because it cannot undo indirect leakage. The CGE literature suggests that the welfare effects of carbon leakage are relatively minor in the first place. Branger and Quirion find estimates of the impact on welfare (usually proxied for by output or GDP) of the unilaterally acting countries range from –1.58 percent to 0.02 percent without a CBA mechanism and from only -0.9.percent to even a positive value of 0.4 percent with a CBA system in place[12]. However, shoring up international competitiveness by means of a CBA regime may be a necessary political condition for implementing any ambitious carbon pricing scheme.

Clearly, there are also costs associated to CBA. The most important two types of costs refer to red tape and to the risk of retaliation.

---

[12] To facilitate comparisons of different policy measures, these welfare impacts do not account for the environmental benefits of lower global greenhouse gas emissions. Partial equilibrium models are typically not able to provide global welfare estimates.

Red tape

On the other hand, any CBA system will involve possibly very substantial administrative burdens that the empirical literature is not accounting for. These come in various guises and depend on the design of the CBA regime. Since no CBA has been put in place in any country, direct empirical evidence on such costs is not available. In the complete CBA regime firms would have to reveal the CO2-content of their products and the information provided by them would have to be verified by authorities. What is more, the more complex a good is, the harder it is to assess the true CO2-content of it. This would require tracking and verifying the entire production chain, both domestically and abroad. This seems a daunting task.

However, there is some empirical evidence on the bureaucratic costs associated to so-called rules of origin (RoOs) required in preferential trade agreements. These rules define under which conditions a good exported from some country is seen to actually originate from that country. For example, EU producers wishing to export duty free to Korea have to satisfy the RoOs laid down in the EU-Korea free trade agreement. These rules can prescribe minimum value added thresholds that exporters have to abide by. Satisfying and documenting those RoOs is costly; often so much that firms prefer to incur tariffs rather than to document the RoOs. Anson et al. (2005), Carrère and Melo (2006), and Estevadeordal (2000) have attempted to quantify these costs and find that they can amount to several percent of the export value. Hence, substantial red tape exists in other trade policy areas as well. Moreover, it would be advisable to concentrate a BCA system on industries which are most heavily affected by carbon leakage and where the unavoidable red tape compares favorably with the benefits of achieving a level playing field. The bureaucratic burden is probably highest with the ‘complete’ BCA described above; alternative regimes such as the OBA-cum-tax scheme save on administrative costs but fare less well in terms of effectiveness and efficiency. The EU will have to strike a delicate balance between administrative costs and effectiveness/efficiency.

Retaliation

Moreover, countries not willing to price carbon emissions themselves may react to a European BCA by imposing countermeasures, for example in form of punitive tariffs. This may, of course, happen regardless of such action is compatible with existing international law or not. The economic damage of such measures by foreign nations can be very sizeable. In fact, the mere threat of imposing tariffs can induce producers to revisit their location decisions. For example, one response of European car manufacturers to US threats to impose car tariffs of 25 percent has been to move favor serving the US market by local production rather than by exports. The damage in real gross value added in the Europe automotive industry of a 25 percent US tariff on cars and car parts is estimated to be about 10.4 billion Euros per year (in prices of 2014) and can easily be more than that in the short run; see Felbermayr and Steininger (2019). A full-blown trade war with the US can cost the EU economy several multiples of this; see Yalcin et al. (2017). And if other countries were to engage in retaliatory tariffs as well, the welfare damage to the EU would go up even further. For example, a recent study reports losses to the EU amounting to almost EUR 250 billion per year in 2016 prices (Bertelsmann Stiftung, 2019). In a comprehensive analysis, these risks would have to be compared to the costs arising from carbon leakage or of a less ambitious climate policy. In any case, the EU is well-advised to minimise the risk of such a trade conflict. One way to ease tensions would be to channel public revenue obtained from a CBA system into a global climate fund or to even rebate it to the exporting countries.

6 Conclusions

The fundamental problem of climate policy lies in the fact that not all countries in the world have adopted sufficiently ambitious policies to mitigate emissions. This may be due to free-riding or to the principle of common but differentiated responsibility. As long as coverage remains incomplete, there is the risk of direct and indirect leakage. The former occurs through international trade in goods and services, the latter through global energy markets.

The EU is the world's largest net importer of CO2 as embodied in traded goods and services. While it is empirically unclear whether, historically, the ETS has driven up those net imports, it is very likely that higher future carbon prices in the EU can drive up carbon imports while reducing territorial carbon emissions. Economic modelling shows that border carbon adjustments (CBAs) can indeed reduce such leakage. However, CBAs may have negative effects on trade partners' terms-of-trade, which may induce retaliation. In their complete form, they may be very bureaucratic to implement.

One promising approach that reduces the risk of retaliation and of red tape but which is less effective would be to maintain the EU's system of output based allocation of free emission permits for sectors prone to leakage but to combine it with a new tax on the consumption of goods produced by firms in those sectors, regardless of whether they originate from the EU or abroad.

References

Aichele, R. and G. Felbermayr (2012), Kyoto and the Carbon Footprint of Nations, Journal of Environmental Economics and Management 63 (2012) 336–354, https://doi.org/10.1016/j.jeem.2011.10.005

Aichele, R. and G. Felbermayr (2015), Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade, The Review of Economics and Statistics, 97(1): 104–115, https://doi.org/10.1162/REST_a_00438

Anson, J., Cadot, O., Estevadeordal, A., De Melo, J., Suwa-Eisenmann, A., and Tumurchudur, B. (2005), "Rules of Origin in North-South Preferential Trading Arrangements with an Application to NAFTA." Review of International Economics 13(3), pp. 501–517.

Arroyo-Currás, Tabaré, Nico Bauer, Elmar Kriegler, Valeria Jana Schwanitz, Gunnar Luderer, Tino Aboumahboub, Anastasis, Giannousakis, and Jérôme Hilaire (2015), Carbon leakage in a fragmented climate regime: The dynamic response of global energy markets, Technological Forecasting and Social Change 90(A): 192-203, https://doi.org/10.1016/j.techfore.2013.10.002

Babiker, M. H. (2005). "Climate Change Policy, Market Structure, and Carbon Leakage". Journal of International Economics. 65(2): 421– 445.

Bertelsmann Stiftung (2019), The World Trade Organization at 25: Assessing the Economic Value of the Rules Based Global Trading System, https://ged-project.de/research/studies/welfare-effects-of-the-wto

Böhringer, C., E.J. Balistreri, T.F. Rutherford (2012), The role of border carbon adjustment in unilateral climate policy: overview of an Energy Modeling Forum study (EMF 29), Energy Econ. 34 (Supplement 2): S97–S110.

Böhringer, C., E.J. Balistreri, T.F. Rutherford (2018), Embodied Carbon Tariffs, Scandinavian Journal of Economics 120(1): 183–210, DOI:10.1111/sjoe.12211.

Böhringer, C. (2014): Two Decades of European Climate Policy: A critical Appraisal. In: Review of Environmental Economics and Policy, Volume 8, Issue 1, pp. 1-17. doi.org/10.1093/reep/ret018

Böhringer, C., K. E. Rosendahl, and H. B. Storrøsten (2017b). Robust Policies to Mitigate Carbon Leakage. Journal of Public Economics, 149(2): 35–46, https://doi.org/10.1016/j.jpubeco.2017.03.006

Böhringer, C., K. E. Rosendahl, and H. B. Storrøsten (2017b). Smart hedging against carbon leakage. Mimeo: University of Oldenburg, https://uol.de/fileadmin/user_upload/wire/fachgebiete/vwl/V-427-19.pdf

Botta, E. and T. Kozluk (2014), "Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach", OECD Economics Department Working Papers, No. 1177, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxrjnc45gvg-en

Branger, F. and P. Quirion (2013), Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies, Ecological Economics 99: 29-39, https://doi.org/10.1016/j.ecolecon.2013.12.010

Brunnermeier, S. and Levinson, A. 2004. Examining the evidence on environmental regulations and industry location. Journal of Environment & Development 13, 6–41. https://doi.org/10.1177/1070496503256500

Carrère, C. and De Melo, J. (2006), "Are Different Rules of Origin Equally Costly? Estimates from NAFTA." The Origin of Goods: Rules of Origin in Regional Trade Agreements. Ed. by Olivier Cadot, Antoni Estevadeordal, Akiko Suwa-Eisenmann, and Thierry Verdier.

Copeland, B. and Taylor, M. 2004. Trade, growth, and the environment. Journal of Economic Literature 42, 7–71.

Ederington J, A. Levinson A and J. Minier (2005), Footloose and pollution-free. Review of Economics and Statistics 87: 92–99.

Estevadeordal, A. and Suominen, K. (2006), "Mapping and Measuring Rules or Origin around the World." The Origin of Goods: Rules of Origin in Regional Trade Agreements. Ed. by Cadot, O., Estevadeordal, A., Suwa-Eisenmann, A., and Verdier, T.

Ferguson, S. and M. Sanctuary (2019), Why is carbon leakage for energy-intensive industry hard to find?, Environmental Economics and Policy Studies 21(1): 1–24.

Felbermayr, G., and Steininger, M. (2019), Effects of new US auto tariffs on German Exports and in industry value added around the world, ifo Institute, http://www.cesifo-group.de/de/dms/ifodoc/docs/pr/pr-PDFs/201902-Felbermayr-Steininger-Automotive-Tariffs.pdf

Friedlingstein, Pierre et al. (2019), Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, https://doi.org/10.5194/essd-11-1783-2019

Global Carbon Project. (2019). Supplemental data of Global Carbon Budget 2019 (Version 1.0) [Data set]. Global Carbon Project. https://doi.org/10.18160/gcp-2019 https://www.icos-cp.eu/GCP/2019

Grosjean, G., W. Acworth, C. Flachsland, and R. Marschinski (2016). After monetary policy, climate policy: is delegation the key to EU ETS reform?. Climate Policy 16(1): 1-25, https://doi.org/10.1080/14693062.2014.965657

Grunewald, N. and I. Martinez-Zarzoso (2016), Did the Kyoto Protocol fail? An evaluation of the effect of the Kyoto Protocol on CO2 emissions, Environment and Development Economics 21(1): 1-22

Jaffe, A., Peterson, S., Portney, P. and Stavins, R. 1995. Environmental regulations and the competitiveness of US manufacturing: what does the evidence tell us? Journal of Economic Literature 33, 132–63.

Levinson, A. (2008), "Pollution Haven Hypothesis" entry in New Palgrave Dictionary of Economics 2nd edition.

Levinson, A (2010), Offshoring pollution: is the United States increasingly importing polluting goods? Review of Environmental Economic Policy 4: 63–83.

Levinson A, M. Taylor (2008), Unmasking the pollution haven effect. International Economic Review 49: 223–254

Nägele, N. und A. Zaklan (2017), Does the EU ETS Cause Carbon Leakage in European Manufacturing? DIW Discussion Paper 1689.

Nordhaus, W. (2015), Climate Clubs: Overcoming Free-riding in International Climate Policy, American Economic Review 105(4): 1339–1370, http://dx.doi.org/10.1257/aer.150000011339

Oswald, A and N. Stern (2019), Why are economists letting down the world on climate change? VoxEU, https://voxeu.org/article/why-are-economists-letting-down-world-climate-change

Partnership for Market Readiness (2015), "Carbon Leakage: Theory, Evidence, and Policy", PMR Technical Note 11. World Bank, Washington, DC., https://doi.org/10.1596/K8516

Peters, G., and E. Hertwech (2008), CO2 Embodied in International Trade with Implications for Global Climate Policy, Environmental Science and Technology 42(5): 1401-1407.

Peters, G. P., Minx, J. C., Weber, C. L., and Edenhofer, O. (2011), Growth in emission transfers via international trade from 1990 to 2008, P. Natl. Acad. Sci. USA, 108, 8903–8908, https://doi.org/10.1073/pnas.1006388108

Sato, M. and A. Dechezleprêtre (2015), Asymmetric industrial energy prices and international trade, Energy Economics 52(1): S130-S141

Stern, Nicholas (2007), The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge, UK.

Yalcin, E., M. Steininger and G. Felbermayr (2017), Global Impact of a Protectionist U.S. Trade Policy, ifo Forschungsberichte 89, Munich: ifo Institute.

PE 603.501
EP/EXPO/INTA/FWC/2019-01/Lot5/1/C/02

Print ISBN 978-92-846-6753-6 | doi:10.2861/02958 | QA-02-20-394-EN-C
PDF ISBN 978-92-846-6752-9 | doi:10.2861/577601 | QA-02-20-394-EN-N