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Benefits and costs of the ETS in the EU, a lesson learned for the CBAM design

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Abstract

The EU is revising its emissions trading system (ETS) and plans to impose a carbon border adjustment mechanism (CBAM) on imports. We evaluate the efficacy of the ETS retrospectively and its anti-competitive effects. We find that the ETS contributed to cut greenhouse gas (GHG) emissions in the EU by 2-2.5 percentage points per year; pricier emissions and more stringent caps accelerated the EU greening process. However, some carbon leakages occurred as declining emissions in regulated industries within the EU were counterbalanced by an intensification elsewhere. Moreover, it burdened companies in regulated industries. For a comparable rise in the emission intensity of production, gross output of companies located in the EU drops more than output of companies outside the EU. In addition, the choice of purchasing high-emission inputs from within the EU translates into a competitive disadvantage for companies located within the EU. The large drop in F-type output when emissions intensity rises might signal their enhanced ability to relocate the production of high-carbon footprints intermediates to non-regulated regions. Outsourcing helps dodging the EU green regulation and the strategy becomes increasingly appealing as the sectoral coverage of the ETS is extended. A careful joint design of the CBAM and the ETS becomes thus crucial to avoid that applying the CBAM to a restricted list of imports while expanding the ETS coverage puts the EU at greater risk of carbon leakages without concretely reducing global emissions.

JEL classification: Q52, Q58
Keywords: GHG emissions, ETS, Carbon leakages, CBAM

Non-technical Summary

The EU plans to become climate-neutral by 2050. The Fit for 55 package is the renewed strategy to step up its fight against climate change and encompasses a revision of the Emission Trading System (ETS) and the introduction of a carbon border adjustment mechanism (CBAM). These tools are devised to strike the best possible trade-off between carbon emissions minimisation and the preservation of production competitiveness in the region, also taking into consideration administrative, technical and political aspects related to their enforcement (European Commission, 2020b).

The remodelled ETS envisages stricter trading rules, extends the industry coverage (in particular to transport and buildings) and cuts more decidedly on emission allowances. More importantly it gradually phases out the exceptions made to emission-intensive and trade-exposed (EITE) industries which were allotted free carbon allowances to prevent carbon leakages. In this context, a CBAM on imports of certain EITE products (cement, iron, steel, aluminium, fertilisers, and electricity) is phased in as of 2026 to guard EU production from the competition of foreign companies operating in unregulated regions (European Commission, 2020b). Importers will buy certificates proportional to the emissions embedded in imports at the ETS market price. By charging the same price, irrespective of the geographical location of emissions and producers, the CBAM aims at placing companies on equal footing when supplying the EU market, offsetting eventual competitiveness losses and thus preventing carbon leakages.

Early literature argues in favour of little adverse effects of the ETS and points to scant empirical evidence of carbon leakages, except in certain high-energy intensive industries (see Chan, Li, and Zhang (2013), Arlinghaus (2015) and Jaraite and Di Maria (2016), Koch and Basse Mama (2016) and Dechezleprêtre, Gennaioli, Martin, Muûls, and Stoerk (2019), aus dem Moore, Großkurth, and Themann (2019)).

This work contributes to the existing literature in three distinct ways. First it enters the debate about efficiency of environmental policies with a new assessment of the ETS benefits in curbing carbon emissions and of its costs in terms of carbon leakages. Second it studies anti-competitive effects on EU industries in a new framework which employs information on sectoral output values and input-output linkages distinguishing across companies by location (within and outside the EU) and ownership structure, (domestic companies and affiliates of multinational enterprises). This distinction enables to verify whether uniformly applied policies still produce differential effects on companies depending on their ownership structure. Finally, because the choice to introduce a CBAM is connected to expectations that companies will act on incentives to dodge costly regulation, the exercise helps informing the debate on whether the Fit for 55 package is likely to deliver on the net-zero emissions

target, under what conditions, and at what costs.

We conduct three distinct empirical studies based on information collected from several sources encompassing ETS carbon prices, emissions traded and those surrendered by regulated industries, emissions by industry in non regulated regions and combine them with information about gross output and input-output linkages of domestic companies and foreign affiliates located in the EU and in other regions. The first analysis measures a positive contribution of the ETS in accelerating emissions declines in regulated industries in the EU. The contribution of the ETS is gauged by the share of traded on total surrendered emissions, a proxy for the degree of stringency of the regulation, and by the declared allowance prices International Carbon Action Partnership (2021). Empirical estimates point to an additional reduction by about 2 percentage points in emissions in $t+1$ per each percentage point increase of this stringency measure at time t. This elasticity increases somewhat after the ETS reform in 2013. Emissions also decline faster in $t+1$ following higher prices for allowances in t.

The ETS efficacy is confirmed when the analysis is extended to non-regulated regions and the equation is specified so to measure the ETS average treatment effect (ATT). However, these achievements came with costs; this second analysis proves non-negligible carbon leakages occurring from the EU to the rest of the world as the emissions reduction in ETS industries within the EU were more than offset by a simultaneous rise in ETS industries outside the EU.

Turning to anti-competitive effects, we find that the output of companies located in the EU is most responsive to emission intensity; that is for an equal rise in emissions per euro worth of production, their output, especially that of MNE affiliates in the EU, drops by more than that of companies operating in unregulated regions. Moreover, output in regulated industries correlate negatively with the exposure to high-carbon footprint inputs if inputs are sourced within the EU and positively when sourced outside the EU, suggesting anti-competitive effects of the ETS. These even strengthen for MNE affiliates in case of high prices of carbon allowances and are therefore expected to become critical as prices of carbon allowances rise further under the extended ETS. Together with the sensitivity of MNE affiliates' output to emission intensity, this evidence suggests a greater leeway of MNEs in reorganising production processes outside the EU borders and advice in favour of extending the application of a CBAM on all regulated productions.

Comparable analyses carried out on unregulated industries show that anti-competitive effects have not been transmitted to the rest of the economy via exposure to high-carbon footprint inputs. Nevertheless, an ex-post joint assessment of the ETS and the CBAM performance is desirable as rising prices for allowances makes the transmission more likely in the future and provide scope for extending the CBAM to production of downstream industries.

1 Introduction and main findings

The EU plans to cut down carbon emissions more decidedly and to step up on greening the economy. An extension and revision of the cap and trading system, known as the Emission Trading System (ETS), and the introduction of a carbon border adjustment mechanism (CBAM) are two key elements of the renewed EU strategy to fight climate change.

Beside stricter trading rules and lower emission caps, the remodelled ETS dismisses the exceptions made to emission-intensive and trade exposed (EITE) industries which were allotted free carbon allowances to reduce risks of carbon leakages. In this context, the EU will as of 2026 gradually introduce a CBAM on imports of certain EITE products which should restrain, if not prevent, EU production from losing competitiveness due to stricter ETS regulation and expanded industry coverage (European Commission, 2020b).

Thereby, while the ETS regulates the internal market for emissions since 2005, the European CBAM is devised to avoid carbon leakages after the enforcement of the new green deal. The scheme envisages importers of certain EITE products, namely cement, iron, steel, aluminium, fertilisers, and electricity, to buy certificates proportional to the emissions embedded in imports at the ETS market price. By charging the same price for emissions as the ETS, the CBAM aims at placing companies on equal footing when supplying the EU market, irrespective of their geographical location, thus preventing carbon leakages from the EU toward the rest of the world. Furthermore green investments in the EU would also be dependent on the determined by the stringency of the new ETS[1] .

Despite its ambitions, the EU is currently responsible for less than 8% of global emissions compared to 44% accounted for by the US and China. Thus, the EU's success in fighting climate change depends ultimately on the ability to export its ambitious green goals abroad by incentivising countries to adopt emission standards comparable to those in place in the EU or by triggering a virtuous circle of spontaneous green technology adoption in non regulated regions. It is therefore of paramount relevance to understand the implications of the *"Fit for 55 package"* in terms of emissions reduction, not just at EU level but also studying global repercussions and eventual carbon leakages.

Early literature on the effects of environmental regulation on competitiveness argues in favour of little adverse effects of the ETS and points to scant empirical evidence of carbon leakages, except in certain high-energy intensive industries. While a distinct review of the extensive literature forms

[1]According to the EU green deal, part of revenues collected from trading emissions and selling certificates will contribute to the Next Generation EU recovery fund which allocates 37% of resources to Green Deal objectives.The ETS auctions' revenues will be increasingly allocated to the EU's Innovation and Modernisation Funds for lower-income EU countries. Member States will remain the main beneficiaries of these resources but they will be required to spend them on climate and energy related projects whereas a fourth of the expected revenues from the new ETS for road transport and building fuels will fund the new Social Climate Fund.

the subject of section 3, we recall here the most important channels. Stringent emissions' regulation can trigger carbon leakages in several ways. By promoting R&D investments in green innovations, it favours the adoption of clean technology, possibly also in non-regulated economies, thus resulting in positive carbon leakages. At the same time, firms faced with rising production costs may decide to offset the competitiveness losses by relocating outside the regulated countries at least part of the production process, or to source inputs from non-regulated regions. Also, consumers may find it convenient to replace the expensive emission-intensive products with cheaper comparable goods produced elsewhere. Each and any of these channels would trigger carbon leakages from the EU toward other regions. Furthermore, a global fall in the price of energy may be triggered by weaker demand in the countries adopting green policies, which could spur, however, stronger demand elsewhere and with it carbon leakages.

Because the introduction of environmental regulation triggers a series of interconnected economic reactions in market players, the identification of specific effects of the ETS becomes tricky. Compared to previous contributions, this work takes a fresher look at the effects of EU environmental regulation on emissions and gross industrial output based on novel data sets and longer time spans. We empirically reassess how the ETS contributed to pacing emissions cuts in the EU, provide an estimate for the elasticity of emissions to carbon prices, evidence of carbon leakages and study the fallout on industry's gross output and competitiveness due to the cap and trading system.

Our findings are meaningful to inform the discussion on whether the Fit for 55 package is likely to deliver the net-zero emissions target and at what cost. In our framework, costs are measured in terms of the negative output differential in the EU versus other regions, for industries directly concerned by the ETS and distinctly for industries indirectly affected through the exposure of their production processes to a rise in production costs in regulated industries. Competitive disadvantages are modelled as a function of the emission-intensity of production and the exposure to emission-intensive inputs.

The study rests on information collected from several sources encompassing emissions, ETS carbon prices, traded and surrendered emissions as well as input-output linkages across countries, sectors and domestic versus foreign owned companies.[2] Because information from different sources could not be

[2]Tonnes of CO2 equivalent greenhouse gas emissions at country-sector level are obtained from two sources - (i) the European Environment Agency (EEA), which also provides the amount of allowances and the amount of surrendered emissions by sector and country since 2005. This is data aggregated on yearly sectoral level mainly based on the Union Transaction Log (EUTL). (ii) the WIOD environmental account containing kilo tonnes of CO2 equivalent units for several more industries (56 sectors and final consumption expenditure by households according to NACE Rev. 2) and 43 countries plus the rest of the world over the years 2000 to 2016 (see Corsatea, Lindner, Arto, Román, Rueda-Cantuche, Velázquez Afonso, Amores, and Neuwahl (2019)). Finally, data on gross output by country and sector, the share of emission-intensive inputs and imports on total were obtained from the OECD AMNE database that distinguishes companies according to domestic and foreign ownership (see Cadestin, De Backer, Desnoyers-James, Miroudot, Rigo, and Ye (2018)). This feature enables an investigation of differences in production models and emission intensity across ownership type. Matching the AMNE and WIOD databases eventually yields 34 sectors and 44 countries. The prices of emissions are collected from the ICAP Allowance Price Explorer (International Carbon Action Partnership, 2021) and averaged yearly.

exactly matched at the finest disaggregation level, the study consists of three distinct investigations.

First, we reassess the effectiveness of the ETS as an instrument to curb emissions in regulated EU industries based on a sample spanning from the year 2000 to 2016. The identification of the ETS effects rests on the heterogeneity in emission intensity and in regulation stringency across time and industries. We expect a negative impact to be increasing with rising stringency and intensity. The log of emissions is modelled as an autoregressive process to account for unidentified forces not concerning exclusively EU countries, for instance shifts in household spending toward light emissions production, green technology innovations but also other environmental policies. We control for industry, country, year unobserved heterogeneity and heterogeneous trend in regulate and unregulated industries/regions and are still able to identify a robust pace of reduction of EU emissions. The ETS stringency is proxied by the share of traded emissions in period t and t-1,i.e. the fraction of total surrendered emissions that companies were not allotted by regulation and had to pay for. Contemporaneous values of this variable may be plagued with endogeneity issues because for given allotments of carbon allowances, when emissions in a sector rise, the share that is traded on the market will also rise. However, the more expensive it becomes for a company to afford pollution the greater the incentive to switch in the future to cleaner technology. Thereby, the effects of the ETS on emission dynamics are captured by the elasticity of emissions to stringency index in the previous period and the equation also control for the emission expenditure in t and in t-1. According to our findings, the ETS has contributed to speed up emissions reductions more than the EU had envisaged: 2.1% on average every year, compared to 1.6% targeted in the period 2005-2016. The pace accelerated further to 2.5% in the third stage after 2013, following the ETS reform. We find that emissions were cut proportionally more in industries with a higher share of traded allowances and the more expensive it becomes for a company to afford pollution the greater the incentive to switch to cleaner technology; this mechanism becomes evident with a year delay and gets reinforced by higher prices for allowances. [3]

These results are cross-checked in a distinct analysis based on the WIOD environmental account. In this second framework, we exploit data on industries' emissions for non-EU countries to test for the presence of carbon leakages due to the ETS. By adopting a difference-in-difference-in-difference methodology, we measure the ETS effects as the change in emissions of regulated industries in the EU following its enforcement and relative to emission changes in the same industries over the same period but in non-regulated countries. Thereby, we model the ETS as a treatment and introduce time and country-sector fixed effects in the attempt to control for the lack of proper sample randomisation.[4] In

[3] The elasticity to the lagged share and expenditure of country-industry emissions are found significant and negative. Thus, when the share of traded emissions on total surrendered emissions rises in t-1, emissions in t are reduced. Similarly, the paces of emissions decline becomes more pronounced when the price paid for polluting increases. We conjecture this occurs because companies adopt cleaner technology or are induced to cut on production and thus on emissions.

[4] The sector and country specific trends control for pre-existing divergence in dynamics

line with the definition in the field literature, we consider evidence of carbon leakages the occurrence of emissions reduction in ETS industries within the EU and simultaneous rise in emissions of ETS industries outside the EU, over the treatment period.

Despite a different empirical modelling, estimation methodology and data, the second investigation confirms emissions trending down at a pace comparable between the two analyses. In both cases the size of the autoregressive coefficient suggests a pace of contraction in EU emissions between 16% and 19% per year with a significant acceleration by 2.6% after 2013. The estimated ETS average treatment effect is 6 percentage points and highly significant, meaning that in regulated EU industries emissions were reduced by more than in the same sectors of unregulated regions following the introduction of the ETS. Interestingly, after 2005, emissions continued to drop globally but surged in carbon-intensive industries outside the EU while declining more decidedly within the EU; this divergence is taken as evidence of carbon leakages.[5]

We finally turn to investigating the question of anti-competitive effects of the ETS on sectoral gross output of companies located in the EU. The analysis distinguishes the impact on EU companies across ownership type, domestic versus foreign owned (D-type versus F-type), aiming to measure whether a neutral policy instrument like the ETS unintentionally favoured production models of global companies that were better equipped to weather changes in emission regulation.

We model sectoral gross output as a function of emission intensity and industry's exposure to emission-intensive inputs, distinguishing them by origin and ownership. The exposure is given by the cost share of emission-intensive inputs on total costs. The improved gross output performance of companies purchasing emission-intensive inputs outside the EU and a worsening of the performance of companies sourcing them within the EU is interpreted as evidence of anti-competitive effects of the ETS, especially so if these are increasing in the EU price for carbon allowances. To account for different channels of transmissions of the ETS to sectoral production processes, empirical analyses are carried out separately for regulated and non-regulated industries.

We find that sectoral gross output in the EU is highly negatively correlated with emission intensity, this relationship weakens greatly or even disappears for companies located outside the EU. Gross output of F-type companies is the most elastic to emission intensity, in both regulated and non-regulated industries, although F-type firms are shown in section 4.3 to be systematically less exposed to carbon-pricing cost shocks than D-type companies in non-regulated industries. We interpret this evidence as ease to relocate carbon-intensive stages of production outside regulated regions; a strategy

[5] These findings are confirmed when we investigate the growth rate of emissions as dependent variable. In this case, more negative rates are identified on EU industries regulated by the trading scheme compared to emissions outside the EU, with an acceleration of the pace of emission reduction measured by the negative coefficient estimated on the lagged rate of emission growth.It is worth emphasising that our estimates of the actual impact of the ETS must be considered conservative to the extent that the ETS propelled energy-saving innovations beyond EU borders.

that stringent EU green regulation would incentivise. Finally, in regulated industries, sourcing high emission inputs within the EU resulted in a competitive disadvantage for EU companies whereas cheaper inputs purchased outside the EU provided a competitive hedge. For F-type companies, this anti-competitive mechanism strengthens with rising EU price for allowances. We do not find robust evidence of anti-competitive effects in non-regulated sectors.

Carbon leakages and anti-competitive effects of the Fit for 55 package should not be underestimated as we find evidence of them already under previous EU regulation. In the current proposal, the CBAM requires importers to purchase certificates for emissions embedded just in a few products and excludes downstream industries. This leaves a door open for dodging new regulation by importing waived production, which still embeds high carbon emission content. The incentive to pursue such strategy are expected to rise with carbon prices as anti-competitive effects strengthen; F-type companies which are already part of a global value chain may find it easier to outsource emission-intensive production stages. Since the EU Commission has already projected prices to grow substantially by 2026 under revised regulation, Europe faces the concrete risk of outsourcing emission footprints without effectively curbing global emissions but putting mostly D-type companies at disadvantage.

For Europe, which only accounts for a small fraction of global emissions and already imports most of the high-carbon footprint productions for domestic absorption, the fact that the CBAM may produce uneven effects across companies and generate shifts of carbon emissions more than net reductions remains the most serious concern of its new green deal.

The remainder of this paper is organised as follows. In section 2, we discuss the features of the ETS and the CBAM more at length. In section 3, we review early contributions to the literature on environmental regulation. In section 4, we describe the data and provide statistics on emission intensities across countries and industries. We show how an identical regulation can produce a differentiated impact on D and F-type companies depending on their production model and discuss the implicit tariff rate in carbon tax and how it distributes across countries and industries. Section 5 is the core of the study, it describes the estimation strategies devised to test ETS effects and discuss our main empirical findings. Section 6 summarises the key messages and concludes.

2 The EU weapons for fighting emissions: ETS and CBAM

2.1 Brief history of the ETS

In 2005, in compliance with the commitments signed in the Kyoto protocol, the European Union introduced the ETS as a pricing mechanism for emissions, a concept first employed in Wisconsin in

1981 (see O'Neil, David, Moore, and Joeres (1983)). In a first phase, companies operating in sectors whose emissions were regulated by the ETS were allotted an amount of allowances equal to their pre-ETS emission levels, referred to as the grandfathering period. Allowances were gradually scaled down to reduce total emissions and the amount auctioned rose over time as a consequence. Major revisions were introduced in the third trading period from 2013 to 2020 with the shift to a single union-wide cap and auctioning as a default method for allowance distribution. In this stage, rules for allocation based on emission performance benchmarks were harmonised.[6]

Under the current EU ETS, a cap is set on the total greenhouse gas (GHG) emissions of electricity and heat generation, energy-intensive industries and commercial aviation.[7] The trading scheme covers 40% of total EU emissions and the members of the European Economic Area, i.e. Iceland, Liechtenstein and Norway, plus Switzerland also participate in it. In the 2005 to 2012 period, the most central registries to the European-wide system were those of France, Denmark, Germany, the United Kingdom, and the Netherlands (Borghesi and Flori, 2018).

Companies buy or trade on the market emissions exceeding their quota within an annually determined aggregate amount of allowances. Each year, they must surrender enough allowances to cover their emissions. A market stability reserve (MSR) absorbs surpluses and avoids too low of a price for emissions. However, until now the EITE sectors, like aviation, were granted free allowances to shield them from carbon leakages. The current proposal to revise the ETS concerns its fourth phase (2021-2030) and envisages a faster pace of reduction in total allowances (to 4.2% from 2.2%) on top of a one-off cut by 117 million allowances needed for de-stocking past accumulated allowances. Freely allocated allowances will terminate as of 2030 after a phasing-out period starting in 2026, when no more free allowances will be allocated to goods concerned by the CBAM. Allowances will also become more targeted and conditional on decarbonisation efforts of companies. The proposal contains the extension of the ETS to building and road transport, to all intra-EU maritime transports and 50% of emissions from extra-EU voyages with the ambitious goal to cut emissions in carbon-intensive industries by 61% on their 2005 level by 2030.

Road transport and building heating will be regulated as of 2025 but through a separate trading scheme that should concern fuel suppliers but not households and car drivers. Allowances will be scaled down to achieve a reduction in emissions by 43% on 2005 levels by 2030.

[6]For further information see the annual reports of the European Commission on the European carbon market European Commission (2020a).

[7]The sectors currently covered are air transport, electricity and combustion, basic metal, namely steel and aluminium, cement, lime, glass, ceramics, and paper products.

2.2 The EU proposal of a CBAM

The "Fit for 55" package, laid out on 14 July 2021, included a proposal for a European CBAM aiming to set an equal playing field between intra-EU production and imports to combat carbon leakage (see European Commission (2021b)), defined as "undesirable consequences of a situation where different jurisdictions pursue climate policies at different ambition levels" (Goerlach and Zelljadt, 2018).[8] The mechanism specifically regulates imports of sectors where the carbon leakage risk is particularly pronounced, i.e. cement, iron, steel, aluminium, fertilisers, and electricity and applies to countries without a comparable ETS. A sector or sub-sector is defined as being exposed to a significant risk of carbon leakage based on two indicators: carbon costs and trade intensity. When production costs rise by at least 5%, as a result of emissions regulation, and trade intensity with non-EU countries is above 10%, then a sector is deemed to be exposed to carbon leakages.[9] Carbon leakages are defined as the ratio of emission increases in non-EU regions in a specific sector over the emission reduction in that sector in the EU (European Commission, 2021c).[10]

The EU importers are required to purchase certificates at a price corresponding to the carbon price prevailing in the EU as determined by the weekly average auction price for allowances under the ETS. Importers must report the quantity of imported goods and the corresponding embedded emissions and must surrender the equivalent number of certificates. Any breach of the regulation requirements will be fined. The system will be fully binding starting in 2026, but the reporting of embedded emissions will start in 2023.

Imports from countries with a comparable carbon pricing mechanism will receive a deduction equal to the price paid at the origin; this is crucial to grant equal treatment and respect the fundamental WTO national treatment principle. However, no partial waivers or compensations are envisaged for imports whose production emitted less GHG than corresponding EU goods.

Upon enforcement of the CBAM, free allowances to companies operating in EITE sectors will cease. Protection of EU industries from foreign competition would not be necessary any longer to the extent that the CBAM sets equal playing grounds for everyone and shields EU industries from the risk of carbon leakages.

Out of the several possible CBAM designs, only those that passed a heuristic multi-criterion feasibility test have undergone, at a later stage, a model based evaluation of the economic impact.[11] The

[8]For a deeper practical discussion of the measure, please refer to Delbeke and Vis (2020).

[9]Carbon costs on output is defined as direct plus indirect costs over gross value added; trade intensity is given by the sum of imports and exports over gross value added plus imports.

[10]They are estimated by the EU commission to stand around 8% and mostly accounted by the rebound of demand for fossil fuels in non-EU mirroring the lower demand in the EU.

[11]The feasibility study considered several aspects ranging from environmental and competitiveness benefits, legal feasibility, technical and administrative feasibility to political and diplomatic feasibility (Marcu, Mehling, and Cosbey,

proposed CBAM was chosen because it outperformed the others in terms of carbon leakage prevention and effectiveness in reducing GHG emissions outside the EU.[12] It has shown to minimize the negative impact on EU investments and consumption while keeping GDP on an unchanged trajectory.[13]

In the proposed mechanism, only imports of a restricted product list, mostly in upstream industries, will be subject to the purchase of emission certificates. Semi-finished and finished products in downstream sectors would be exempted. While risks of carbon leakages in downstream industries seem modest according to models of production and value chains, based on JRC-GEM-E3 researchers admit that such conclusions are model-dependent and a rise in carbon prices makes leakage more likely and worrisome. For instance, recent research based on detailed disaggregation at product level confirms a low risk of carbon leakages in downstream industries, which may anyhow concern between 5% and 15% of manufacturing production, respectively, at a price of 35 euros and 70 euros per tonne of CO2 (see Stede, Pauliuk, Hardadi, and Neuhoff (2021)).

Beside economic considerations, the EU legislator was also concerned with technical and administrative feasibility at this stage. A mechanism extended to semi-finished and downstream production in EITE sectors was discarded primarily because of its complexity. However, sturdy increases in EU carbon prices are indeed expected as a consequence of the ETS revision, thus raising doubts about the opportunity to limit the application of the CBAM to just a few goods.

In what follows, we take a retrospective approach and evaluate to what extent carbon leakages were already incentivised by the implementation of the ETS. The exercise proves useful to assess the opportunity of implementing the European CBAM as currently devised. We distinguish the impact on the sectors directly regulated by the ETS and indirect spillovers on the other industries; the latter estimation helps identifying possible carbon leakages on downstream industries.

2.3 Compliance with international law: WTO and Kyoto protocol

The CBAM corresponds to a unilateral trade measure not agreed upon at the WTO or in other international fora such as the Paris club. In principle, it could therefore originate litigations and

2020).

[12]Along with other five alternatives mechanisms, the consequences of the envisaged CBAM were evaluated in terms of emissions, within and outside the EU, risks of carbon leakages, GDP, consumption, investment and consumer prices, based on a computable general equilibrium model with inter-sectoral linkages and explicitly modelling the energy sector for (European Commission, 2021a).

[13]The evaluated mechanisms were all found to have negligible repercussions on consumer prices to the extent that the concerned products represent a very limited share of industrial production. The same study forecast the price for emissions that would prevail in 2025 and 2030 in the six options evaluated, under the implementation of the *fit for 55% package* provisions. In particular, the forecast are conditioned on the CBAM gradually being phased-in as of 2026 and fully operative, i.e. without free allowances, by 2035 at earliest, emission caps declining faster and industries covered by an ETS getting extended to building and transports.

retaliations if it is found to breach WTO legislation.[14] If strongly opposed by other countries, this instrument could prove self-defeating as trade restrictions imposed in response to its implementation may impair instead of restore EU competitiveness, thus jeopardising the export potential of EU industries. [15]

Environmental preservation is included in the rather short list of public goods worth a waiver from compliance with WTO legislation, together with safety and health. In these cases, member states are entitled to impose trade measures with the sole obligation to notify the WTO beforehand (see, for instance Pauwelyn and Kleimann (2020)). Members do it continuously but very rarely have these measures originated lawsuits.[16]

While the environment safeguard receives a general exemption, trade measures aiming to preserve industry competitiveness must comply with WTO key principles. The EU CBAM is actually a hybrid between the green remit of fighting carbon leakages and the goal of compensating competitiveness losses of domestic industries due to stringent emissions regulation. Moreover, certain aspects of the proposal of the European Commission suggest that the EU's first goal was to preserve competitiveness.

Indeed, imports of energy efficient EITE products with smaller carbon footprints than corresponding EU production are still subject to the adjustment mechanism. However, importing more of them, the EU could achieve a greater domestic and global reduction in GHG emissions at no risk of carbon leakages. This aspect could for instance form the object of confrontation at the WTO by the most efficient countries.[17]

The current proposal of the CBAM is designed to minimise the risk of originating WTO litigations. Being applied indiscriminately to all countries and proportionally to their emission content, to all companies, the CBAM fulfills the most-favoured nation (MFN) principle which prohibits discrimination between like products on the basis of the country of origin. Besides, the CBAM puts domestic and foreign production on even footing since imports would be charged the price prevailing in the ETS for their carbon footprint and would obtain a rebate proportional to the price paid at home,

[14]Indeed, WTO litigations occur also on trade measures agreed multilaterally, however they mostly concern the interpretation of agreements or the implementation of trade restrictions.

[15]There are few general exemptions to WTO legislation. Beside health and safety purposes, members are entitled to impose trade measures for environment protection purposes notifying their introduction at the WTO. Nevertheless, no exceptions are granted to members whose additional aim is preserving competitiveness when fighting climate change. Members have been increasingly introducing trade restrictions to safeguard the environment; there have been more than 11,000 notifications by WTO members of environmental trade measures between 2009 and 2019, corresponding to about one in six of all notified measures. Only in 10 cases these have originated a litigation.

[16]Similar trade measures encompass the establishment of minimum energy efficiency requirements for household goods, introduction of licensing schemes to limit trade in endangered species of wildlife, creation of taxes applicable to hazardous chemicals and supporting policies for the development of low-carbon technologies. When challenged at the WTO, the issues concerned concealing industrial protection from foreign competition under the application of a general exemption. More than 15% of all notifications made to the WTO include environmental objectives. Out of the 11,000 measures notified between 2009 and 2018, only 10 have originated a WTO dispute.

[17]There are very few countries not covered by the ETS whose production are more efficient than comparable EU production, the UK being a noteworthy example.

when a comparable trading scheme is enforced by the origin country. On these grounds, legal scholars tend to agree that the extension of the ETS to imports, as the CBAM proposes to do, complies with WTO law.[18] [19]

Despite informal consultations and careful revisions of the proposal, it cannot be excluded that the CBAM will originate litigations and retaliations at the detriment of EU foreign trade and industry competitiveness which it was meant to protect in the first place. Lack of international coordination among leading players, i.e. the US and China, differences across national ETS, differences in prevailing ETS market prices as well as differences in the methodology computing the emissions embedded in units of foreign production may generate applicability issues and controversy with EU trading partners. It cannot be excluded that some exporters would consider the computations of emissions embedded in imports - still to be agreed upon - as illegitimately restraining competition or treating their production unfairly, thereby resorting to the WTO to rule over the case.[20] And in this context a strong form of coordination among countries, like linking their national ETSs is under consideration. It would represent a long run solution by reducing the scope for a CBAM and at the same time facilitating the convergence of methodology applied in computing emissions at national ETS (see Verde, Galdi, Borghesi, Füssler, Jamieson, Soini, Wimberger, and Zhou (2021)). Overall, the consensus in the literature is that designing a CBAM correctly is challenging (see Cosbey, Droege, Fischer, and Munnings (2019) and Delbeke, Dombrowicki, and Vis (2021)), but when this is done right, compliance with WTO regulations is possible (see Horn and Mavroidis (2011) and Mehling, van Asselt, Das, Droege, and Verkuijl (2019)).

3 Literature review

A general concern of economic policies targeting the environment has always been a possible resulting decline in the industry's competitiveness. Perhaps the earliest literature review on environmental regulation and competitiveness comes from Jaffe, Peterson, Portney, and Stavins (1995). Focused on

[18]Alternative border adjustment mechanisms were discarded as likely non-compliant with WTO principles. Granting an export subsidy to EU carbon-intensive production may have turned into unfair support of domestic over foreign production, banned by WTO law. On the same tone, since the computations of emission per unit of production is questionable and may be challenged at the WTO, the list of imported products subject to the European CBAM is, at least initially, limited to goods where carbon leakages are particularly pronounced.

[19]While no official negotiation was undertaken, informal discussions about the CBAM have taken place among WTO members during meetings of the trade and environmental committee, suggesting that the EU has pondered other countries' standpoints and is aware of what aspects are most problematic. As of October 2021, the CBAM has been discussed during dedicated meetings of the trade and environmental committee at the WTO three times already. Other countries had the opportunity to raise eventual concerns and, according to internal officials, the EU kept a listening mode on each occasion.

[20]The treatment of imported products which are less emission intensive than comparable ones in the EU is a thorny issue; in this case the EU could not claim that the CBAM is meant protect the environment and avoid carbon leakages since replacing domestic production with imports would not harm but benefit the environment and the general exemption may not be called in.

US manufacturing, they find that there is little evidence for an adverse effect of stricter environmental policies on competitiveness. Building on this, Dechezleprêtre and Sato (2017) review more recent empirical cross-country literature on the competitiveness effects of environmental regulation. They assert that the conclusions of Jaffe et al. (1995) have become more robust over time and admit that a risk of carbon leakage exists in certain sectors, particularly very energy-intensive ones with limited ability to pass-through costs.

The ETS is a system of marketable permits, a concept first analysed in depth by Hahn and Hester (1989). Its main goal is a reduction of emissions, the success of which we investigate for the entirety of the EU and the most extended time horizon possible. An early look at the EU's biggest economies suggests that lower emissions resulted among French (Wagner, Muûls, Martin, and Colmer, 2014) and German manufacturing firms thanks to enhanced energy efficiency (Petrick and Wagner, 2014). In a review of literature on the EU ETS and comparable regional mechanisms globally, Haites (2018) confirms that emissions subjected to the EU ETS have indeed declined. However, he also points to the difficulties in disentangling the effects of the ETS from other policies and developments, which we address with our econometric approach.

Dechezleprêtre, Nachtigall, and Venmans (2018) manage to quantify the emission reductions resulting from the EU ETS. Their estimate for the period 2005 to 2012 stands at around 10%, with the bulk stemming from the second phase. Successful abatement is confirmed in early analyses by Ellerman and Buchner (2008), Abrell, Faye, and Zachmann (2011), Anderson and Di Maria (2011) and Ellerman, Marcantonin, and Zaklan (2016) as well as in a literature review by Venmans (2012), while Gloaguen and Alberola (2013) cannot clearly attribute the CO2 reduction observed in the EU to the ETS. In their review of ex-post literature on the EU ETS, Martin, Muûls, and Wagner (2016) stress that much of the existing literature has focused on correlations rather than causalities. They still assess the impact of the ETS on emission reductions as robust. Bayer and Aklin (2020) stress that a credible threat of a future rise in the price can incentivise firms to reduce emissions even when prices are still low. They quantify CO2 reductions resulting from the ETS at 3.8% of total emissions in the period 2008 to 2016. Verde et al. (2021) provide an elaborate comparison of the EU ETS with other ETSs in use around the globe.

The risk of undermining EU competitiveness and eroding market shares as a consequence of green policies was also debated at length at the time of the ETS enforcement. Back then, Oberndorfer and Rennings (2006) sustained that the ETS was not designed to boost Europe's economy but to ensure that Europe's CO2 emissions reach Kyoto targets at minimal costs for EU industry. Thus, negative effects were considered unavoidable but their literature review of simulation studies on the impacts of the EU ETS concludes about modest effects on competitiveness, especially compared to alternative

Kyoto-based regulation scenarios. Fifteen years later, we can check their conclusions against actual data.

A plethora of ex-post studies finds hardly any significant negative effects of the ETS on the competitiveness of subjected firms in the two initial phases, e.g. Chan et al. (2013) in a study of the cement and iron and steel industries, Arlinghaus (2015) in a literature review, and Jaraite and Di Maria (2016) in a study of Lithuanian firm-level data. A further threat often presented in this context is that of firm relocation as a response to tighter regulation. In the context of the EU ETS, the literature largely shows that this has not materialised (Koch and Basse Mama (2016) and Dechezleprêtre et al. (2019)) or that firms have even expanded their local asset base (aus dem Moore et al., 2019). Only Borghesi, Franco, and Marin (2019) find an increase in outbound foreign direct investment (FDI) activity for the Italian manufacturing sector. On top of using more recent data for our analysis of competitiveness effects, we also contribute to this body of research by investigating output effects as a function of emission intensity in inputs on domestic owned and foreign owned firms separately.

Martin, Muûls, de Preux, and Wagner (2014) study the free allocations granted at the start of the ETS roll-out and find that these lead to inefficient overcompensation compared to the optimal allocation that the authors identify for circumventing carbon leakage and especially keeping employment in the EU. Relying on data from the Community Independent Transaction Log, Betz and Schmidt (2016) find that the bulk of firms participating in the ETS did not transfer allowances in Phase I, putting into question the instrument's efficiency in the earliest stage. Inefficiencies are also confirmed by Karpf, Mandel, and Battiston (2018). In an analysis of the ETS' impact on firm performance, the literature review by Martin et al. (2016) and empirical analysis by Marin, Marino, and Pellegrin (2018) find no negative effects on several firm-level performance indicators, while Dechezleprêtre et al. (2018) even identify a positive one on revenue and fixed assets.

Building on the empirical consensus that competitiveness effects of the ETS have been limited, Joltreau and Sommerfeld (2019) set out to analyse the reasons behind this observation. The main argument they identify is the high amount of freely allocated certificates in phases I and II. The findings of a contained impact of the EU ETS on both firm competitiveness and carbon leakage are confirmed in a recent broad review of the relating econometric literature by Verde (2020), who concludes that there is no general evidence for effects in either direction. As a caveat, he mentions that most evidence only refers to the phases up to 2012. Our work adds to the debate by using more recent data, as described in 4.1.

Given the limited implementation of CBAMs worldwide, the literature on the topic is more scarce and theoretical compared to the mostly empirical work on the ETS described above. The earliest literature review we encountered, by Horn and Mavroidis (2011), investigates the impacts of border tax adjustments, i.e. import tariffs to reduce emissions abroad. It does not find significant support for the desirability of such a measure. Antimiani, Costantini, Martini, Salvatici, and Tommasino (2013) confirm this conclusion in a general equilibrium model analysis.

However, a larger body of literature assesses a CBAM as a useful instrument for combating carbon leakage. In comparisons of different anti-leakage policy options, Fischer and Fox (2012) and Böhringer, Carbone, and Rutherford (2012) identify CBAMs as the most effective measure for leakage reduction and as the comparably best option in terms of global cost effectiveness. A meta analysis of 25 early studies by Branger and Quirion (2014) suggests a mean reduction in carbon leakage of 8% with a CBAM compared to only an ETS. Cosbey et al. (2019) review the legal and economic literature on the CBAM, which yields that the functionality of a CBAM hinges critically on its design and that many issues surrounding CBAMs are still largely under-researched. Our work aims at bringing some more light into the darkness of research on CBAM.

More specific insights on CBAMs come from Böhringer, Balistreri, and Rutherford (2012), who find that when an economy unilaterally adopts such a measure, it can mitigate adverse impacts on EITE industries and reduce carbon leakage, shifting the burden of emission reduction towards the countries that export to the abating economy. Burniaux, Château, and Duval (2013) employ a global general equilibrium model to highlight that border adjustments reduce carbon leakages if they operate on international trade competitiveness and that a CBAM would not necessarily soften the output losses incurred by the domestic emission-intensive industries.

More recent analysis also finds that a CBAM is indeed an appropriate measure for reduction of carbon leakage (Böhringer, Carbone, and Rutherford, 2018) and emissions in general (De Nederlandsche Bank, 2021) but the effect on prices of . The De Nederlandsche Bank (2021) authors also conclude that both prices of imported and domestically produced goods will rise as a result and that the effects can differ largely between EU member states. Contrarily, Delbeke et al. (2021) conclude that a CBAM would only offer limited protection from carbon leakage. Currently, to our knowledge, there is only one CBAM in place worldwide, which is based in Calfornia since 2013 but only accounts for interstate electricity trading . First research that investigates the Californian case pleads for a careful design of the CBAM but finds some positive effects on emissions regardless (Fowlie, Petersen, and Reguant, 2021).

4 Data and stylised facts

4.1 Data sources

We employ data obtained from several sources for our empirical study. Trade flows between countries and sectors are obtained from the analytical Activity of Multinational Enterprises (AMNE) data set by the Organisation for Economic Co-operation and Development (OECD) and described in Cadestin et al. (2018). As this is a combination of national AMNE statistics with the OECD Trade in Value-Added databases, it not only differentiates production, trade, and value-added by sector and industry, but also by domestic versus foreign firm ownership. AMNE data are available over the period 2005-2016 for 60 economies, one of them being the rest of the world, and 34 industries classified according to the ISIC Rev. 4.

For emissions, we use two independent sources. First, we take tonnes of CO2 equivalent units from the European Environment Agency (2021), which structures and aggregate data mostly based on the EU Transaction Log (EUTL). CO2 equivalent units is based on the global warming potential of different greenhouse gases. The CO2eq unit measures the environmental impact of one tonne of these greenhouse gases in comparison to the impact of one tonne of CO2. The EUTL is centrally run by the European Commission and records all transactions taking place within the trading system. It contains more than 15,000 stationary installations in 29 sectors (aviation, combustion of fuel, and 27 energy intensive ETS industries) reporting under the EU emission trading system, as well as 1,500 aircraft operators. The EEA then aggregates the information from the EUTL to a sectoral level and provides data by country, sector and year on verified emissions, allowances and surrendered units. The second source is the World Input-Output Database (WIOD) Environmental Accounts provided by the European Commission's Joint Research Centre (Corsatea et al., 2019). This data set contains CO2 emissions in kilo tonnes for 56 sectors and final consumption expenditure by households according to NACE Rev. 2 and 43 countries plus the rest of the world over the years 2000 to 2016.

For compatibility, we combine several WIOD sectors to obtain similar industries' definition as in the AMNE. The data concerning the 15 countries included in the AMNE but excluded from the WIOD are grouped and added to the rest of the world, eventually yielding 34 sectors and 44 countries for both databases. Furthermore, the sectors in the combined data set are more aggregated than the actual ETS sectors. Hence, we are forced to use an approximation. Specifically, we come up with five sectors in which the bulk of ETS, but not exclusively ETS, sectors are covered. The five sectors are "Coke and refined petroleum products", "Basic metals", "Other non-metallic mineral products", "Electricity, gas, water, waste and remediation", and "Transport and storage".[21] According to Gores,

[21] It could be argued that "Transport and Storage" does not fall under the ETS, because only aircraft carries that also

Cludius, Graichen, Healy, Nissen, and Zell-Ziegler (2019), the EU ETS also includes the production of pulp, paper, and cardboard as well as specific chemicals.[22] As these make up only smaller parts of the wider AMNE sectors "Paper products and printing" and "Chemicals and pharmaceutical products", respectively, we consider them non-ETS.

We obtain data for emissions prices from the International Carbon Action Partnership (2021) (ICAP), which compiles this data from official sources in all applicable jurisdictions globally on a monthly basis.[23]

4.2 Emissions per unit of production: EU vs non EU countries

We compare the amount of emissions per unit of production, e.g. the emission rates/intensities, across sectors in the EU and non EU countries. Emission intensities are obtained as the ratio of emissions by sector-country, taken from the WIOD environmental account, over sectoral production by sector-country pairs as reported in the OECD-AMNE database. This exercise provides an overview of industries where there is room for improvement and highlights leading and lagging economies in terms of emission efficiency. Thus, it provides an overall idea of countries where most energy efficient companies may be located and that could eventually envisage triggering a WTO dispute over CBAM enforcement.[24]

In a situation when countries exhibit all very similar emission efficiency, the risk of carbon leakages is low; ideally we would like to see the same emission rates prevailing everywhere, especially for production in sectors which are highly tradeable. Countries exhibiting large positive gaps compared to the EU - i.e. low emission efficiency rates - may become the destination of carbon leakages through production relocation. Table A2 in the appendix reports in rows the ratios of EU over no-EU energy intensity rates for each given sector.

The EU scores rather well overall. It is among the medium to least polluting regions in every sector; it stands out by emission efficiency in the transport sector (H) with only Turkey and Switzerland faring better. The Swiss economy is the most emission efficient in almost every sector. However, as an ETS member it will be waived from the CBAM. It has thereby no incentive to start a WTO confrontation on the mechanism design.

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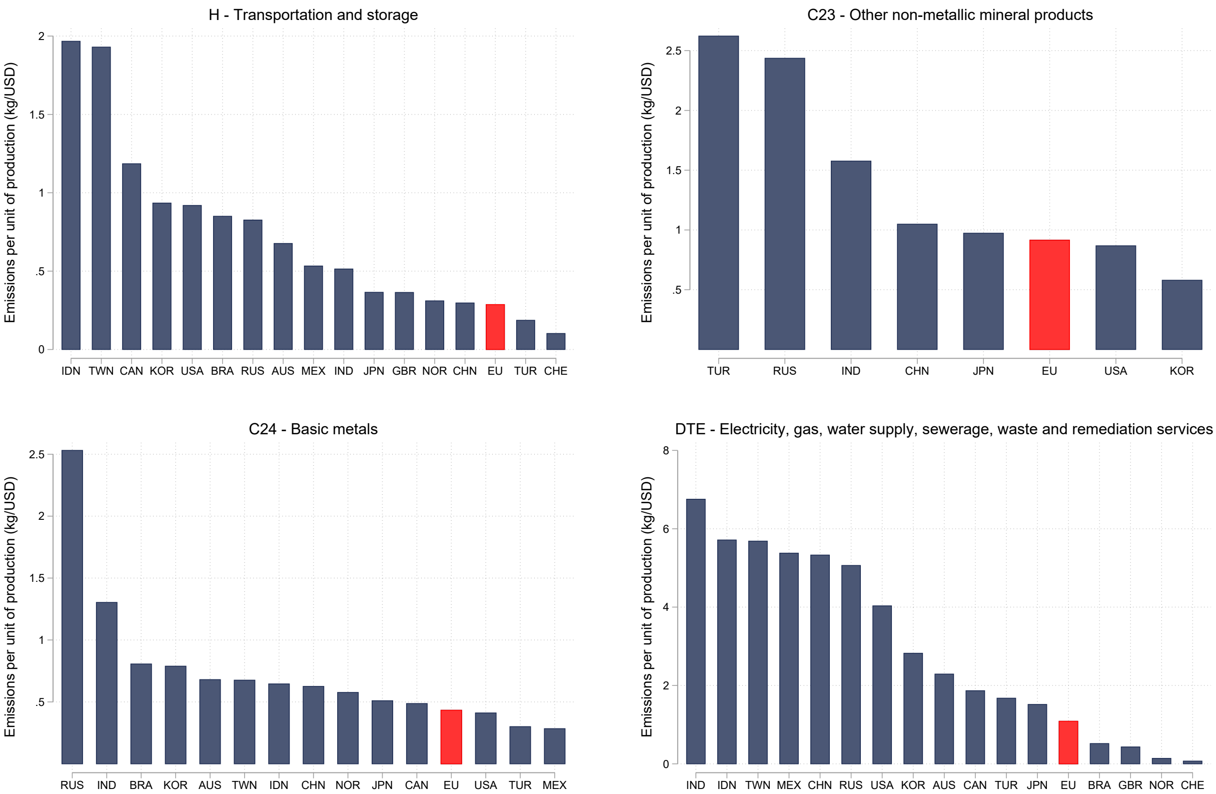
received a generous amount of free allowances are covered under the ETS. We repeated the analysis treating "Transport and Storage" as non-ETS and leaving it out of the estimations; our main findings are not affected significantly by any of the change.

[22]Specifically, these are carbon black, nitric acid, adipic acid, glyoxal and glyoxylic acid, ammonia, bulk chemicals, hydrogen and sysnthesis gas, as well as soda ash and sodium bicarbonate.

[23]Besides the (ICAP) prices, there are at least two alternative sources for emission prices delivering comparable yearly prices: The ICE exchange quotations of EU allowances (EUA) futures and the European Energy Exchange prices.

[24]Emissions rate were computed based on sectoral output by country; this variable is opportunely winsorised to remove sectors whose production is negligible from country standpoint (below 1%), unless the country was identified among the top five global producers for that specific sector.

Figure (1) Ranking countries by emission intensity in high-emissions sectors



Notes: Emission intensity rates are given by emission in tonnes of CO2 equivalent units by sector and country over gross value added (in Million USD) by sector and country. The WIOD environmental database provides data on emissions, the AMNE-OECD contains gross value added; last available year, 2016

It is worth mentioning that differences across countries in sectoral emission intensities can in part also reflect within-sector specialisation that may be skewed toward high emission businesses. Natural endowments, historical patterns and other reasons unrelated to countries' efforts in fighting climate changes may explain sectoral specialisation patterns. The analysis of emission intensity differentials of EU with respect to other countries confirms that overall the set of sectors regulated by the ETS coincides with those most exposed to carbon leakages. Only "Mining and extraction of energy producing products" and "Chemicals and pharmaceutical products"comes close to the ETS sectors (see Figure 1 and Table A1 in Appendix A.1).

The EU can be several times less polluting than emerging countries but also definitely less than other large advanced economies. For instance, the US are not an efficiency champion and score rather low especially in some key ETS sectors. The amount of carbon emissions per unit of production in transport and storage and for electricity and gas in the US is more than three times as high as in the EU. The few exceptions are identified in industries where the production has been largely relocated outside the US, like computers and electronics, beside specific metal productions.

Country-wise, there exists a divide between emerging and advanced economies; Indonesia is systematically less efficient than the EU in every but three sectors, China's energy efficiency is constantly below EU efficiency. Canada and Russia, net exporters of energy products, feature a production structure with high emission intensity, thereby lagging behind the EU in terms of efficiency achievement in two thirds of all industries. Overall, unsurprisingly, carbon leakages risks concentrate in ETS sectors and tend to occur primarily toward emerging economies.

4.3 Do foreign and domestic owned firms differ in terms of exposure to emission-cost shocks?

Production processes can differ along several dimensions. In this section, we investigate the presence of systematic heterogeneity in emission intensity of domestic owned versus foreign owned firms. The latter are likely to be more involved in international fragmentation of production processes, a condition that facilitates input substitution across sources. We show that their production processes appear less emission-intensive than those of comparable domestic companies, possibly owing to the outsourcing of the most polluting production stages.

The revision and the extension of the ETS will entail higher total production costs for EU companies but to a different extent depending on their emissions' exposure. Similarly, the CBAM will entail extra costs for EU companies sourcing their emission-intensive production inputs from outside the EU.

We compare the share of emission intensive inputs on total production costs, e.g. emission exposure, across type of ownership (domestic, D versus foreign, F) and geographic location of companies (EU versus non EU countries), industry by industry; this is useful in gauging the impact of greener regulation on industries-companies performance.[25]

In industries regulated by the ETS, i.e. "Coke and refined petroleum products", "Basic Metals", "Other non-metallic mineral products", "Electricity, gas, water supply, sewerage, waste and remediation services" and in "Transport and Storage", foreign owned companies based in the EU constantly spend a greater share of total production costs on energy intensive inputs than domestic owned companies do (see Figure A2 in Appendix A.2). Thereby, they are more exposed than domestic owned companies to the new EU green regulation and to a rise in carbon prices. Peculiarly, this occurs systematically in regulated industries and never in unregulated ones where emission intensity of foreign owned companies are either comparable or below domestic ones (see Figure A3). The exposure differentials between foreign owned and domestic owned companies may entail greater output sensitivity of F-type operating in the EU to rising energy intensity; they have more pronounced economic incentives to relocate/outsource the heavy polluting production stages when more stringent green regulation is enforced.

While a key goal of the "EU fit for 55 package" proposal is the implementation of neutral green policies, not discriminating across countries and type of companies, unbiased policy instruments may unintentionally favour certain companies over others depending on the flexibility of the production model, the possibility to relocate certain stages abroad and the exposures to carbon-pricing cost shocks.

Section 5 examines empirically whether differences in production processes have translated into differential patterns taken by gross output of foreign and domestic owned companies within and outside the EU following the introduction of the cap and trading EU system.

4.4 The implicit carbon tax of a universal EU-CBAM

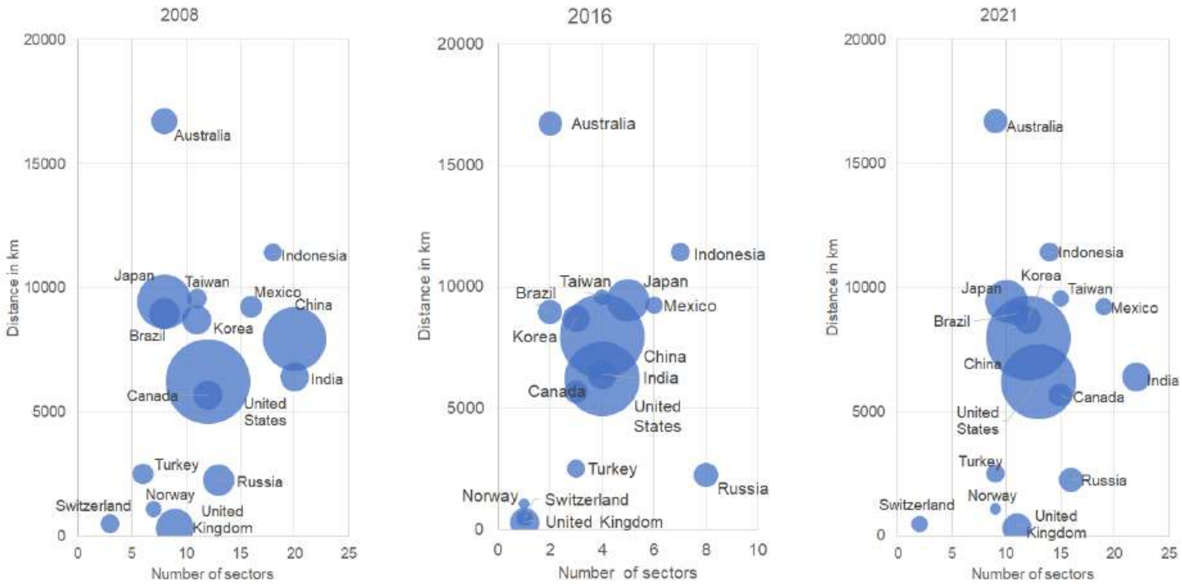
In principle, the EU CBAM may be re-designed. It can be extended to downstream production or to any imported item, the price of certificates could be calibrated on emission intensity of the originating country or differentiated across sources depending on their sectoral emissions per unit of production. Several of the possible amendments to the current proposal will probably not happen because they are cumbersome, demand extra paperwork and most likely will be opposed politically and at the WTO; however, we still perform a thought experiment by computing the tariff equivalent rates that would have been applied if the CBAM was implemented in 2005 on all imports, proportionally to

[25] Emission-intensive inputs as those with emission caps and trading system regulated under the ETS.

their emission intensity and irrespective of the origin.

Tariff equivalent computations are based on the average price prevailing on the market for ETS in a given year and on the emission-intensity of productions by sector-country pair. The tariff equivalent rate is elicited by the product of emission intensity and the price for emissions. It must be interpreted as the fraction of a US dollar paid in tariffs for each US dollar worth of production.[26]

Figure (2) Countries' positioning in terms of number of sectors with tariff-equivalent above 3 percent



Note: Countries' positioning on the vertical axis is the distance from the EU and on the horizontal axis indicates the number of sectors for which the tariff equivalent rate from imposing a universal CBAM would be above the 1% threshold. Beside distance, the other typical determinant of bilateral foreign trade is the economic mass of countries. It provides a rough idea of trading partners' importance in EU imports and thus helps gauging how serious the repercussions on EU trade, price of imported goods, production cost would be from the enforcement of the CBAM on a specific origin country. The economic size of partners defines the size of the bubbles. Variation in countries' positioning between the leftmost (2008) and and central (2016) panel reflect changes in emission intensity by sector and in carbon prices, whereas variation between 2016 and 2021 only reflect price changes, as the last year of available emission intensity is 2016.

We find a high degree of heterogeneity in tariff equivalent rates across countries and sectors. Unsurprisingly, the highest rates are associated to production of emerging markets with Indonesia, Mexico and especially Russia and China standing out. The two elephants in the climate change room are the US and China. Not only do they account for half of extra-EU bilateral trade but, despite some improvement of China over time, they are also characterised by emission efficiency rates below those of advanced economies (see Figure 2).

At the average carbon price of 2016, the highest equivalent tariff rates would have been 9.2 cents per USD worth of production for electricity imported from Mexico and 5.5 cents from India and Indonesia, whereas the largest equivalent tariff rate on manufacturing would have been applied on "other non

[26]The tariff equivalent is obtained multiplying the emission prices per t-Co2 equivalent by the country-sector emission intensity. When defining emission intensity, only the value added of intermediate production is considered. In mathematical terms: $Teq_{c,j,t} = e^{int}_{c,j,t} * p^e_t$ with $e^{int}_{c,j,t} = \frac{e_{c,j,t}}{y_{c,j,t}}$

metallic mineral products" originated from Turkey (1.7 cents per USD worth of production).

However, tariff equivalent rates would be three times as high at the ETS prices of 2021 and bound to rise as the trading scheme is extended and emission are capped more decidedly (see for example Bruninx and Ovaere (2022)). In particular at an emission price of 80 US dollars per Tonnes of CO2 equivalent units, like the price in 2021 but twelve times the price in 2016, about a third of the product-sector combinations would be subject to a tariff of 3% or more with the highest tariff-rate charged on electricity. This compares with 2016 when only 9% of product-sector would have gone subject to a 1% tariff.[27]

5 Empirical methodology and results

We carry out three distinct empirical investigations; the first two evaluate the ETS performance in terms of carbon emissions curbing, the second quantifies also the occurrence of carbon leakages. Carbon leakages are measured by the ratio of emission changes in countries with less stringent regulation over emission changes in the adopting countries; positive leakages rates occur when emissions in regulated industries increase outside the EU while declining within the EU.

Carbon leakages can produce extensive effects on the economy through several channels.[28] The most investigated and debated is the competitiveness channel, which operates when, as a consequence of stringent emissions regulation (a) companies switch suppliers of emission-intensive inputs and intermediates in favour of non-regulated regions; (b) the stages of production with high carbon-footprints are relocated outside the regulated region; and/or (c) consumer demand shifts toward cheaper but more polluting foreign productions. In the case of EU regulation, as more competitive extra-EU imports displace domestic production, GHG emissions could rise on a global scale, eventually above the pre-regulation status quo.

The third estimation studies the anti-competitive effects of the ETS on EU companies by assessing the repercussions on gross output of EU industries. Being able to distinguish the emission-intensive inputs across origins, our analysis identifies the competitive advantage accrued by purchasing high-emission inputs outside the EU and how this grows when carbon prices rise. We are first to distinguish the impact of the ETS on domestic (D-type) versus foreign owned (F-type) companies, shedding light

[27]The threshold is arbitrarily selected considering a protection rate which generates either non negligible erosion of profit margins or a significant increase of prices if the tariff is passed onto downstream industries/final consumers.

[28]Positive leakages from the EU to the rest of the world can arise when energy prices fall, as a result of EU companies cutting down on emission intensive inputs, stimulating demand for fossil fuels elsewhere. However, the energy market-price channel only operates when regulated economies are sufficiently large that a change in their fossil fuel demand alters global market equilibrium. Conversely, the green-tech adoption channel operates when carbon pricing spur innovation which, if adopted in unregulated regions, produces beneficial leakages. Moreover the income redistribution channel tend to generate ambiguous effects whose sign cannot be ascertained ex ante as they promote shifts in consumption preferences, terms of trade and income redistribution toward low carbon footprints consumption.

on the consequences of green regulation on the structure of production processes.

5.1 Emission curbs associated to the ETS

Did the ETS prompt reductions in emissions beyond green-tech progress and other anti-pollution measures?
We use the information about the quantities of emissions traded in the EU and their price as instrument to identify the ETS efficacy. We model the log level of emissions at time t in country c and sector j ($y_{c,j,t}$) as a function of its value at time $t-1$, the share of emissions traded by companies in each industry ($sh_{em,j}$) and the implicit tariff paid for them ($p_{em,j}$), at time t and $t-1$ (see equation 1). The share of emissions traded (sh_{ems}) in each regulated industry since 2005 is a measure of regulation stringency. This is obtained subtracting the allotted allowances from total surrendered allowances and dividing by total surrendered allowances. We use the term stringency index because the more stringent the regulation for a given industry, the larger is the part of emissions auctioned or traded by companies with insufficient allowances to cover for total emissions. [29]

The equation is estimated for all industries regulated by the ETS and the estimation employs the EEA data (see section 4.1). As a robustness check the equation is also specified in log changes of emissions; in this case, besides the log changes of emissions in $t-1$, the equation controls for the log level of emissions in $t-1$ (not displayed in equation 1).

$$\begin{aligned} y_{c,j,t} = \rho y_{c,j,t-1} + \beta_1 sh^e_{c,j,t} + \beta_2 sh^e_{c,j,t-1} + \beta_3 sh^e_{c,j,t\geq 13} + \beta_4 sh^e_{c,j,t-1\geq 13} + \\ + \beta_5 p^e_{t-1} sh^e_{c,j,t-1\geq 13} + \alpha_c + \alpha_j + \alpha_t + t_j \end{aligned} \tag{1}$$

The specification includes country (α_c), time (α_t), sector (α_j) unobservables and industry trend (t_j) to control for confounding factors, which might interact with emission developments like other environmental policies and green-tech transformations. Finally, we augment the equation to separate any eventual differential effect brought up by the ETS reform in 2013. Specifically, we search for a change in the pace of EU emissions reduction that would be captured by the coefficient on the share of traded emissions, its lag and its interaction with emission prices since 2013 ($\beta_3, \beta_4, \beta_5$ in equation 1).

In a system of capped emissions any increase in the demand for emissions should lead to an increase in demand for allowances, thus forcing regulated industries to trade a greater share of their

[29] Our stringency index is potentially subject to a caveat. It won't capture the excess of demanded allowances on those available for trade on the market and would in these cases under-report the actual tightness. Nevertheless,in the period under analysis an excess demand is unlikely to have occurred.

total surrendered emissions. Because of this, higher contemporaneous emissions would go hand in hand with an increase in the share of traded emissions, resulting in a positive relationship with y which is plagued with reverse causality issues that bias the estimates of β_1 and/or β_3.

At the same time, past prices for allowances and past values of the stringency index would affect future emissions but be unaffected by future emission developments, thus proving a good instrument to measure the ETS efficacy in promoting cleaner production. This can be read in the estimates of β_2, β_4 and β_5 in equation 1).

Table (1) The ETS performance assessed by its stringency and the cost of traded emissions

VARIABLES	(1) $log(em.)$	(2) $log(em.)$	(3) $\Delta log(em.)$	(4) $\Delta log(em.)$
$log(em)_{t-1}$	0.835***	0.813***	-0.0863***	-0.106***
	(0.00805)	(0.00825)	(0.00626)	(0.00670)
$emtraded_t$	0.0298***	0.0291***	0.00631***	0.0124***
	(0.00192)	(0.00190)	(0.00159)	(0.000975)
$emtraded_{t-1}$	-0.0203***	-0.0196***	-0.000874	-0.00963***
	(0.00173)	(0.00171)	(0.00137)	(0.000976)
$ETS3 : emtraded_t$	-0.000970	0.00507**	0.0126***	
	(0.00220)	(0.00233)	(0.00175)	
$ETS3 : emtraded_{t-1}$	-0.00368*	-0.00517**	-0.0171***	
	(0.00209)	(0.00212)	(0.00157)	
$ETS3 : em.cost_t$		-0.000172**		0.000239***
		(7.06e-05)		(6.25e-05)
$\Delta log(em)_{t-1}$			-0.282***	-0.286***
			(0.00953)	(0.00962)
$ETS3 : em.cost_{t-1}$				-0.000403***
				(7.27e-05)
Observations	5,408	5,408	4,941	4,941
Number of id	459	459	453	453
Country FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry Trend		YES		YES
R2 overall	0.889	0.893	0.431	0.419
R2 between	0.968	0.964	0.167	0.143

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the log of emissions measured by tonnes of Carbon dioxide equivalent obtained from the European Environment Agency (EEA). emtraded is the difference between allocated allowances and total surrendered units divided by total surrendered units and multiplied by 100. em.cost is the interaction of emission price and the share of traded emissions. ETS3 is a binary variables equal to unity since the year 2013. Industries are the ones covered by the ETS (29 industries). The analyses cover the period 2005-2020. Unit of observations is sector-country-year.*

Results based on equation 1 are displayed in table 1. Albeit positive, the autoregressive term is smaller than one, indicating a declining emission rate (see columns (1) and (2) of Table 1). The coefficient on the autoregressive term summarises the effects, among others, of technological progress, shifts in consumers preferences, other environmental regulation but encompasses also indirect effects of the ETS. To such extent, our estimates of the ETS efficacy are to be considered conservative. The estimations in log differences confirm that emissions trended down at faster rates in sectors-countries starting out with high emission levels (negative coefficient on the lagged emissions growth rate, see columns (3) and (4)). Furthermore, the negative sign on the lagged log difference points to a decrease in the growth rate of emissions over time.

Finally, the estimation measures a 2% fall in emissions for any percentage point increase in stringency (e.g. share of traded on total surrendered emissions at t-1 multiplied by 100) and suggest that the ETS became more effective as the cost for allowances rose after the reform in the third stage (coefficient rise to 2.5% after 2013 see column (2)).

5.2 Diff-in-diff-in-diff of ETS effectiveness

An alternative test of the ETS effectiveness can be formulated as a diff-in-diff-in-diff estimate and interpreted as an average treatment effect on the treated (ATT), relying on the information contained in the WIOD environmental account. This data source reports annual emissions levels for regulated industries and other industries, in EU countries but also in several non-EU economies. Thereby, it allows researchers to device a test for the presence of differential patterns in emissions since 2005 in EU regulated industries relative to unregulated industries and compare it to the same differential in regions without emissions trading system.

The diff-in-diff methodology has been widely applied to diverse economic context in past decades, despite the fact that precise assumptions about data behaviour must hold to obtain unbiased estimates of the ATT. Researchers split the data under analysis into treated and untreated units, borrowing from medical terminology and assume the two resulting samples to be randomly selected from a super-population. Furthermore, treated and untreated units are assumed to exhibit parallel trends prior to the treatment (for an in depth discussion and econometric solutions see Roth, Sant'Anna, Bilinski, and Poe (2022)).
Random sample selection and parallel trends are assumptions that risk to be violated when estimating the effectiveness of measures specifically devised to curb GHG emissions. It could be argued that sectors with high emissions intensity have been targeted by the EU policymakers, as we showed in section 4.4, and that regulated industries or unregulated countries exhibit more pronounced emission trends. Under these circumstances the analysis risks to underestimate the policy effectiveness. However, we address or at least mitigate these potential shortcomings enriching the standard ATT specification with extra terms that tackle the eventual biases. The equation specifies the log of emissions and the log change of emissions in country c, sector j, at time t ($y_{c,y,t}$) as depending on their own value at $t-1$.

The canonical country-sector fixed effects ($\alpha_{c,j}$) and year fixed effects (see equation 2) capture eventual pre-existing differences in treated versus non treated units that may arise from non-randomness of sample selection. Moreover the baseline specification has been extended to include industry and country trends, in the attempt to control for heterogeneous trends in regulated versus unregulated sectors as well as additional unobserved confounding factors.

In our specifications the test of the ETS effectiveness builds on the interaction of three binary indicators cutting the sample along the temporal, sectoral and country dimensions. Specifically, α_3 is the coefficient on the interaction of the three dummies, respectively identifying years post-2005, the industries whose emission are regulated under the ETS and EU countries. This corresponds to D3 in table 2 and captures the average cut of emissions associated with the ETS.

Finally, as recommended in the literature, we further enrich the specification to condition the ATT on additional determinants. Specifically we controls for stochastic emission trends that differ in regulated and unregulated countries and industries before and after the treatment. This is achieved with a triple interaction of emissions at $t-1$ times country dummies times industry dummies. The differential reduction rate in emission in the EU (treated group) relative to non-EU countries is read in the coefficient of the interaction of the triple dummy with lagged emissions (see δ, corresponding to D3 times $log(em)_{t-1}$, and D3 times $\Delta log(em)_{t-1}$, depending on the specification).[30]

Any pre-existing difference not captured by fixed effects and different trends and not controlled for by the autoregressive terms may bias the estimated coefficient.

Finally the specifications in log differences remove eventual different deterministic trends.

$$\begin{aligned} y_{c,j,t} = \alpha_{c,j} + \alpha_t + \alpha_{1(t\geq 2005)} + \alpha_{2(t\geq 2005,j\in ETS)} + \alpha_{3(t\geq 2005,j\in ETS,c\in EU)} + \\ + t_j + t_c + \{\rho + \gamma_{(t\geq 2005,j\in ETS)} + \delta_{(t\geq 2005,j\in ETS c\in EU)}\} y_{c,t-1} \end{aligned} \tag{2}$$

Like the analysis carried out in section 5.1, the autoregressive term confirms the existence of a general negative trend in emissions; reassuring estimates are close to each other. The negative coefficients on the $D3$ terms are evidence that the ETS succeeded in taking the EU on a faster green track in regulated industries compared to non regulated industries and non-EU countries. The average effect is estimated to be around 6 percentage points. Controlling for differential trends undermines the robustness of the $D3$; however the specification points to the ETS having accelerated to about 2.5 percentage points the emission decline rate in the regulated sectors in the EU (see column 2 in Table 2).[31]

[30] Alternatively, we checked for the presence of different developments in emissions controlling for separate stochastic trends specifically within and outside the EU and separately for regulated and unregulated industries (interaction of within/outside EU x regulated/non-regulated x lagged emissions). Three out of four estimated coefficients on emissions at $t-1$ are comparable, about 0.83, except for unregulated industries outside the EU exhibiting a somewhat slower pace of reduction in emissions (0.90). The ATT effect of the ETS is still modelled as the interaction of lagged log emissions with three binary indicators of treated period, treated sectors and treated regions. The coefficient estimated on the tripled interacted lagged emissions shows that the ETS accelerated the process of emission reduction in regulated industries within the EU by 1.8%. Table and results will be made available upon request.

[31] It is worth recalling that the identification strategy rests on country-sector-time features of the ETS, therefore effects produced by other policies could only be confounded with the ETS effects if they acted on the same set of industries and countries over the same period.

Table (2) Diff-in-diff-in-diff estimates of the ETS performance - efficacy and carbon leakages

	$\log(em)_t$		$\Delta\ \log(em)_t$	
	(1)	(2)	(3)	(4)
$\log(em)_{t-1}$	0.841***	0.837***	-0.164***	-0.165***
	(0.00368)	(0.00405)	(0.00411)	(0.00413)
$\Delta\ \log(em)_{t-1}$			-0.0263***	-0.0600**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0446***	-0.0792***	-0.000657	-0.000221
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0513**	-0.00491	0.0460*	0.0437*
	(0.0170)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0604**	0.167	-0.0625**	-0.0620**
	(0.0206)	(0.105)	(0.0232)	(0.0232)
D1 X $\log(em)_{t-1}$		0.00573***		
		(0.00167)		
D2 X $\log(em)_{t-1}$		0.00269		
		(0.00903)		
D3 X $\log(em)_{t-1}$		-0.0254*		
		(0.00989)		
D1 X $\Delta\ \log(em)_{t-1}$				0.0451*
				(0.0225)
D2 X $\Delta\ \log(em)_{t-1}$				0.124*
				(0.0625)
D3 X $\Delta\ \log(em)_{t-1}$				-0.210**
				(0.0659)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interaction of D1 with a dummy taking on value 1 for regulated (ETS) industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries. Regulated (ETS) industries are Coke and refined petroleum products (C19), Basic metals (C24), Other non-metallic mineral products (C23), Electricity, gas, water, waste and remediation (DTE), and Transport and storage (H). 34 industries from 44 countries (including RoW) for 2000-2016 are covered.*

We find as downside of the ETS, evidence of positive carbon leakages from the EU towards unregulated countries; this is signalled by the coexistence of positive α_2 and negative α_3 and measured by the difference in these two estimates.

Indeed, emissions in EU regulated sectors declined at an increasing rate, according to the negative sign taken on by δ (see D3 X $log(em)_{t-1}$ in column (2) and D3 X $\Delta log(em)_{t-1}$ in column (4) of Table 2) but rose elsewhere. The ETS proved effective in curbing emissions at home but has promoted an intensification of emission outside the EU, sabotaging in part its original mission.

To complete our analysis and as robustness check we also investigate to what extent some of the regulated sectors have been responsible for the negative carbon leakages more than others by replicating the estimation of equation 2 augmented for an additional interaction term. D4 captures the differential effect associated to a specific regulated sector relative to the average ETS effect. In this case we find that carbon leakages have occurred with equal intensity in every regulated sector, except "Coke and refined petroleum products", where the analysis points to no occurrence of carbon leakages; point estimates are reported in appendix B.1.

5.3 The anti-competitive effects of the ETS on EU industries

What costs did the EU bear for greening its economy? In this concluding empirical exercise we move away from assessments of ETS performance in delivering on its mandate and study its consequences for EU sectoral production of regulated and unregulated industries.

We innovate on previous empirical contributions by distinguishing the effects on domestic (*D-type*) and foreign owned companies (*F-type*). While we do not expect the ETS to be beneficial or detrimental on businesses depending on their ownership; according to evidence provided in section 4.3, F-type firms in the EU rely more heavily on emission intensive inputs in regulated sectors and less heavily in non-regulated industries than D-types do. Thus F-type firms, which are already participating in global outsourcing, might have been more concerned by rising emissions prices. Therefore, these firms may find a greater advantage in outsourcing to non-EU suppliers or relocating certain stages of production in unregulated regions as the ETS is extended unless a CBAM is properly designed to prevent it.

The analysis verifies whether the ETS created, already in the past, incentives to substitute emission-intensive inputs produced in the EU with those produced in countries where a comparable trading scheme for emissions was not in place.

The exercise employs information from three different sources: the AMNE database, the WIOD environmental account and the ICAP carbon prices. Besides sectoral gross output and imports, the input-output multi-region database (AMNE) maintained by the OECD, is used to compute the exposure to emission-intensive inputs (e.g. inputs of ETS regulated industries), originated within and outside the EU. The distinction of sourcing regions is instrumental to measuring whether or not the output effects of the exposure to high carbon-footprint inputs depends on the producers of such inputs being subject to the ETS.

Since the WIOD environmental accounts only provide the amount of emissions by country-sector pairs without distinguishing across D and F-type of companies, the emissions were allocated, within each country-sector, to D and F-type companies based on their respective share of energy inputs in total country-sector costs. It is also worth recalling that because the sample spans only the post-ETS period (2005-2016), the identification of the impact of regulation on industries' gross output rests on sectoral and geographic heterogeneity but cannot distinguish whether certain patterns pre-dated the introduction of the ETS.

In this context, sectoral gross output is modelled as a function of its emission intensity (e.g. GHG emissions per euro worth of output). More importantly, the estimation includes measures of the exposure to environmental regulation computed as the fraction of emission-intensive inputs (e.g. whose production is regulated by the ETS) in total costs for intermediates broken down by origin and ownership. We expect that an anti-competitive effect due to the ETS would harm more those companies that source preferentially emission-intensive inputs from within the EU relative to companies that resort to supplies from outside the EU. Finally, interaction terms between the price for EU carbon allowances and these input shares measure whether rises in carbon prices widen the competitive wedge amplifying the anti-competitive effects on most exposed industries. We also account for industries' heterogeneity in value added by including the ratio of costs for intermediate inputs on total gross output. The equation specifies the logarithm of sectoral gross output by ownership type ($y_{c,j,o,t}$) as a function of emission intensities ($e^{int}_{c,j,o,t}$), total inputs cost on gross output ($inp_{c,j,o,t}$), the cost share of inputs from regulated sectors ($inp^{e}_{c,j,o,t}$), the first difference of the log of emission prices p^e at time $t-1$ and $t-2$ and the interaction of p^e with the cost share of regulated inputs as proxy of the exposure to carbon taxation in the EU for $t-1$ ($p^{e}_{c,t-1} * inp^{e}_{c,j,o,t-1}$). The specification accommodates four distinct elasticities of gross output to emission-intensive inputs depending on their geographic origin and ownership (EU, non-EU, home, foreign).

Furthermore, the market price for allowances enters the specification lagged to avoid reverse causality. For a given technology, demand of emission-intensive inputs grows faster when output does, all the more if clean energy supply is limited, prompting rises in the pricing of carbon allowances.[32]

Finally, in order to clean the estimates from the effects of several confounding factors, sector-country-ownership and time fixed effects as well as sectoral and country trends are included. These factors are bundled in unidentified fixed effects. We can't exclude that such controls also partially pick-up part of the effect of the ETS. Positive carbon leakages due to green innovation spurred by ETS enforcement are captured by such controls.[33]

$$\begin{aligned} y_{c,j,o,t} = \alpha_{c,j,o} + \alpha_t + T_j + T_c + \gamma_1 \Delta ln(p^{e}_{t-1}) + \gamma_2 \Delta ln(p^{e}_{t-2}) + \boldsymbol{\beta_{eu,o}} * e^{int}_{c,j,o,t} + \boldsymbol{\lambda}_{eu,o} * inp_{c,j,o,t} \\ + \sum_{p \in D,F}^{m \in EU,NEU} \boldsymbol{\delta^{m,p}_{eu,o}} * inp^{e}_{c,j,o,t} + \sum_{p \in D,F}^{m \in EU,NEU} \boldsymbol{\theta^{m,p}_{eu,o}} * p^{e}_{t-1} * inp^{e}_{c,j,o,t-1} \end{aligned} \tag{3}$$

Equation (3) is estimated for industries whose emissions are regulated by the ETS and separately for *other industries*, because the ETS may operate on them through different channels. Non-linear

[32] In the appendix we report results obtained when analysis focuses on the log changes of sectoral output.

[33] EU companies saw their activity capped by emissions allowances, they were led to innovate production processes, adopt green technology or shift purchases of emission-intensive inputs away from companies subject to the cap and trading scheme.

responses can emerge in productions subject to emissions caps as restructuring and production relocation are more likely. Production in other industries, on the other hand, is affected by the ETS to the extent that regulated industries passed on part of the costs from greening their production or from buying allowances.

The main empirical findings concerning gross output in regulated industries are discussed in section 5.4 and those of other industries in section 5.5.

The output tables of the estimations display in rows the estimated coefficients per type of company (D-type and F-type) and geographic location (EU versus non EU) and in columns the coefficients estimated on each regressor. For instance, the row labelled *EU-D* at the column *emisugo* reports the elasticity of gross output to emission intensity of domestically owned companies in the EU. All the estimated coefficients, reported in a single table, are obtained from a single regression. When the coefficient in the specification is one across type of ownership-country, like for emission prices (*dlogplag*) we report it repeating its value across rows.

5.4 The case of regulated industries

A first result of our analysis points to gross output declining with emission intensity everywhere (see column (1) of Table 3, where *emisugo* corresponds to $e^{int}_{c,j,o,t}$ in equation (3)); the elasticity is however larger for EU production (the different coefficients in column *emisugo* of Table 3) for F-type companies whose production processes featured higher GHG emission rates than D-type. The gross output of D-type companies in regulated sectors declines by 0.7% for a 10 percentage point increase in emission intensity; those of F-type companies by 2%. A negative elasticity of gross output to emission intensity is identified also in D-type companies outside the EU, where a system for capping emissions was not in place. The parameter may thus reflect shifts in consumers demand toward low-emission products or other autonomous changes. Nevertheless, this evidence does not survive the specification in first differences where output growth declines with emission intensity only for EU regulated industries (see table A10). [34]

In regulated industries pricier carbon emissions affect sectoral output negatively and output growth with one or two-period lags (see the coefficients in column *dlogplag* and *dlogplag*2 of table 3, which corresponds to $\Delta ln(p^e_{t-1})$ and $\Delta ln(p^e_{t-2})$ in equation (3)). More importantly, we find evidence that companies sourcing emission-intensive inputs from within were at a competitive disadvantage, especially those located in the EU, while sourcing from outside the EU boosted their performance.

[34] The specification in first differences of log levels confirms that output growth (see A10) declines in emission intensive industries only for EU located companies and more strongly for F-type companies. On the contrary, sectoral output growth is found unaffected outside the EU.

Specifically, D-type companies performed relatively better when emission-intensive inputs were sourced outside the EU and worse when sourcing from F-type within the EU (see row EU-D, column (4) and (5) in table 3 and column (5) in table A10). For F-type companies operating in the EU, the disadvantage of sourcing from within EU appears significant and with the expected sign only in the interaction with prices (columns (7) and (9) in table 3). Thereby, purchasing emission-intensive inputs from with the EU (both from D and F-type companies) widens the competitive disadvantage as the EU price for carbon emissions grows (see also row EU-F in Table A10 at the columns (7) and (9)). Similarly, the advantage of sourcing from outside the EU for F-type companies in the EU widens as emission allowances prices rises (see row EU-F column (10) in Table A10); however, such advantage does not exist unless carbon prices are high.

This evidence is even starker in the estimates obtained with the specification in first differences. In general, comparable analyses carried out on gross output growth rates return even stronger evidence in favour of the hypothesis that F-EU companies bore the largest consequences from environmental regulation in the EU.

We can't be sure whether the findings we obtain are due to restructuring of production processes outsourcing of high carbon footprint production stages or bulk offshore of production. Nevertheless, we can interpret them as consequences of the ETS because of their positive correlation with carbon prices and because the elasticity of F-type gross output (and output growth) to emission intensity becomes more negative when ETS regulation becomes more stringent in stage three (since 2013). We report in Tables A12 and **??** of the Appendix section the detailed estimates obtained when the output elasticity to emission intensity is allowed to change after 2013. Output becomes less responsive to energy intensity in D-type companies (by 0.03 percentage points for each percentage point increase in energy intensity) whereas, as expected, industry's output outside the EU is unaffected.

Table (3) Gross output as a function of exposure to ETS regulation by location and ownership: the case of regulated industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			input share domestic		input share foreign		pshare input domestic		pshare input foreign	
	emissions / gross output	inputs / gross output	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS
non-EU-D	-0.00130***	0.000227	0.00825	0.0120	0.0269	-0.0333	0.00324	-0.00669**	-0.00912	0.00213
	(0.000361)	(0.00379)	(0.118)	(0.0103)	(0.244)	(0.0236)	(0.0445)	(0.00311)	(0.0915)	(0.00792)
non-EU-F	-0.000233	0.00116	0.0690	0.00386	-0.498***	0.0205	0.0136	-0.000860	0.0330	-0.0177*
	(0.000149)	(0.00272)	(0.0551)	(0.00604)	(0.160)	(0.0325)	(0.0168)	(0.00155)	(0.0529)	(0.00970)
EU-D	-0.000719***	0.00371	0.00918	0.0446***	-0.0524***	0.0224	0.000359	-0.00445	-0.00695**	-0.00904
	(0.000121)	(0.00231)	(0.00587)	(0.0138)	(0.00826)	(0.0341)	(0.00194)	(0.00468)	(0.00277)	(0.00704)
EU-F	-0.00204***	0.00254	0.00717*	0.00244	-0.0171	0.0260	-0.00426***	-0.000338	-0.0103*	0.0529***
	(0.000202)	(0.00206)	(0.00425)	(0.00823)	(0.0166)	(0.0216)	(0.00123)	(0.00294)	(0.00595)	(0.0101)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Number of observations 3,397. Number of id 434. The dependent variable is the logarithm of sectoral gross output in industries whose emissions are regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends. Rows indicate the interaction of different region-origin-dummies with explanatory variables in the columns (1)-(10). (2) are emissions per unit of production, (3) intermediates per unit of production, (3)-(6) inputs from regulated sectors per unit of production from different regions and origins, (7)-(10) multiply (3)-(6) with the price of emissions. (11) and (12) are the log of emission price at t-1 and t-2, respectively. 44 countries (including RoW) for the years 2005-2016 are covered. Regulated (ETS) industries are Coke and refined petroleum products (C19), Basic metals (C24), Other non-metallic mineral products (C23), Electricity, gas, water, waste and remediation (DTE), and Transport and storage (H). 34 industries from 44 countries (including RoW) for 2000-2016 are covered.*

5.5 The case of non regulated industries and ETS spillover on other industries

The anti-competitive effects identified in the analysis of ETS on regulated industries might have been partly transmitted to other industries, depending on the extent to which the cost-shock was passed on downstream producers and their exposure to emission-intensive inputs. We continue to measure sectors' exposure to high-carbon footprint inputs by the share of emission-intensive on total inputs costs. The equation specification remains also unchanged.

While the focus in this section shifts on the relationship between gross output (and output growth) and emission intensity in remaining industries, stylised facts appear rather comparable to those of regulated sectors, some of them are even strengthened while others seems weakened. In particular we are able to confirm that in *other industries*:

1. the output of companies located within the EU appears most sensitive to emission intensity, especially those of F-type companies where output falls by 0.78% for an increase in emission-intensity by 1 percentage point.[35]
2. the higher the exposure to emission-intensive inputs sourced within the EU (outside the EU) from D-type companies the lower (the higher) the gross output (see column 3 and 4 of Tables 4 and A11, especially rows EU-D and EU-F).[36]
3. in the specification in log differences the anti-competitive effects of sourcing from D-EU companies widens with rising prices for emission allowances (see row EU-D, column (7) in Table 4).

Higher prices for emission allowances negatively affect also output of non-regulated industries. However, in non regulated industries the exposure to emission-intensive inputs is more mixed. For instance, buying emission intensive inputs from F-type outside the EU also represent a disadvantage for gross output performance, whereas sourcing emission-intensive inputs from F-type located in the EU turns out potentially as an advantage (columns (6) and (5), table 4) .

In this context, the presence of carbon leakages concerning non regulated industries would be signalled by a negative coefficient on the emission intensive inputs sourced from EU companies and a positive one on inputs sourced outside the EU; it could potentially concern both EU and non-EU companies. Actually empirical estimates show that:

4. the more emission intensive inputs were sourced from D-type companies located outside the EU, the stronger gross output of EU companies. Same evidence holds true for F-type located outside the EU.

[35]The finding is only confirmed on F-type companies in the log difference specification

[36]The finding is only confirmed on inputs from D-non EU companies in difference equation.

5. sourcing more emission intensive inputs from D-type EU companies worsened the output performance only of D-type EU companies (column (6), row EU-D).
6. F-type located outside the EU were at strong disadvantage when sourcing intensive inputs from F-type located in the EU (but it tends to attenuate as the carbon prices increase, possibly due to substitution of sources) and a more negative one as price increase with the D-type located in the EU (columns (5), (7) and (9), row non-EU-F).

The current proposal for the CBAM limits the requirement to buy certificates for emissions embedded in imports just to importers of metals, fertilisers and electricity and does not extend to importers of downstream components which have been produced using the same inputs but transformed abroad and then imported. The EU commission has found, in its empirical assessment of the CBAM that an extension to downstream industries is too difficult to implement and too cumbersome to manage. Moreover, the risk and economic damage from carbon leakages was considered very limited. The analysis we carried on the performance of unregulated industries seems to confirm that risks of carbon leakages are milder compared to those we identified on the directly regulated industries but a reassessment will be in order as carbon allowances becomes increasingly expensive.

Table (4) Gross output as a function of exposure to ETS regulation by location and ownership: the case of non regulated industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			input share domestic		input share foreign		pshare input domestic		pshare input foreign	
	$\frac{\text{emissions}}{\text{gross output}}$	$\frac{\text{inputs}}{\text{gross output}}$	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS
non-EU-D	-0.00197***	0.00130	0.0880	0.000809	0.0132	0.0277	-0.0613	-0.00203	0.0348	0.0123
	(0.000639)	(0.00231)	(0.102)	(0.00596)	(0.146)	(0.0258)	(0.0452)	(0.00138)	(0.0654)	(0.00758)
non-EU-F	-0.00107*	0.00193	-0.00974	0.0167***	-0.310***	0.00572	-0.0710***	0.0000656	0.149***	-0.0111
	(0.000612)	(0.00163)	(0.0509)	(0.00502)	(0.0779)	(0.0228)	(0.0204)	(0.00136)	(0.0332)	(0.00736)
EU-D	-0.00595***	-0.00232*	-0.00826**	0.0348**	-0.000142	-0.132***	0.00179	0.0108**	-0.000244	-0.0149
	(0.00155)	(0.00120)	(0.00415)	(0.0148)	(0.00916)	(0.0408)	(0.00115)	(0.00487)	(0.00310)	(0.0106)
EU-F	-0.00788***	0.000118	-0.000300	0.0322***	0.0235**	-0.0896***	-0.00486***	-0.00272	0.00372	0.00815
	(0.00174)	(0.000927)	(0.00417)	(0.00800)	(0.0100)	(0.0151)	(0.00128)	(0.00270)	(0.00314)	(0.00562)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Number of observations 19,612. Number of id 2,516. The dependent variable is the logarithm of sectoral gross output in industries not regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends. Rows indicate the interaction of different region-origin-dummies with explanatory variables in the columns (1)-(10). (2) are emissions per unit of production, (3) intermediates per unit of production, (3)-(6) inputs from regulated sectors per unit of production from different regions and origins, (7)-(10) multiply (3)-(6) with the price of emissions. (11) and (12) are the log of emission price at t-1 and t-2, respectively. 44 countries (including RoW) for the years 2005-2016 are covered. Regulated (ETS) industries are Coke and refined petroleum products (C19), Basic metals (C24), Other non-metallic mineral products (C23), Electricity, gas, water, waste and remediation (DTE), and Transport and storage (H). 34 industries from 44 countries (including RoW) for 2000-2016 are covered.*

6 Conclusions

This work contributes to the literature on the effects of environmental policies in the EA in three main ways. First, it provides a novel assessment of the ETS efficiency; second, within a single framework it highlights the trade-off between achievements in terms of reductions in GHG emissions and costs in terms of carbon leakages. Third, it spotlights the consequences of the ETS adoption for output and competitiveness of companies located in the EU, with effects distinguished by ownership structure (domestic and foreign owned) and by sector of production (regulated and non-regulated industries).

The effectiveness of the ETS and its anti-competitive effects are grounded on more recent and more detailed information, which combines several sources. Two distinct analyses find evidence that the ETS promoted additional reduction of carbon emissions within the EU. We have also uncovered the occurrence of carbon leakages, in line with conclusions by Dechezleprêtre and Sato (2017). Adding to the evidence of Borghesi et al. (2019), we also shed lights on the anti-competitive effects of the ETS. The observed gross output losses of EU industries are more pronounced in regulated industries for companies sourcing high carbon footprint inputs from within the EU.

To the best of our knowledge, we are first to identify a differential impact of the EU environmental regulation on domestic and foreign owned companies also in connection to their exposure to high-carbon footprints inputs. We find evidence of negative effects on gross output of D and F-type companies located in the EU and operating in regulated sectors when emission intensity of production rises. Moreover, when the share of energy intensive inputs sourced from within the EU rises, companies seem to face a competitive disadvantage as their output is negatively affected. Conversely sourcing polluting inputs from non regulated regions seems to provide a competitive hedge as their output expands. For F-type these effects are significant only when the price for carbon allowances is high.

We also find that F-type companies feature a greater responsiveness of their gross output to emission intensity. This means that for every increase in emissions per unit of US dollar worth of production, the gross output of F-type companies both in regulated and non regulated industries contracts more markedly than D-type. In our interpretation, this might be due to their ability to restructure production processes and relocate most polluting stages outside the EU rather than simply the production lost to environmental regulation.

Overall, even policies uniformly applied on all companies and devised to be neutral in any other aspect but emissions, while targeting high-polluting companies, may end up penalising those with less footloose capital. To such extent, the differential effects on gross output of environmental regulation may reflect the occurrence of carbon leakages outside the EU without a concrete reduction in global emissions.

From the EU standpoint, designing environmental policies that incentivise their adoption beyond EU borders is strategic but is also a concrete challenge. Promoting the EU green strategy abroad faces two important limitations: first the most polluting inputs are already produced abroad and imported into the EU, second the EU share in global emissions reaches just 8%, while US and China together produce 44% of global emissions. On these grounds, non-EU firms may prefer to find alternative markets without tariffs rather than embracing a low-emission technology which complies with the EU regulation.

Based on our empirical evidence, anti-competitive effects were spurred by ETS in regulated industries; the combination of a revised ETS and a limited application of the CBAM would grant EU companies leeway to import free of charge high-carbon content inputs, thus undermining the ultimate goal of reducing global emissions. Nevertheless, while a bulk application of the CBAM would be more effective at reducing the risk of anti-competitive effects and carbon leakages, technical details and red-tape burden make this option non-viable. Political clashes could be faced if trading partners retaliate and the CBAM could ultimately end up harming more than preserving the competitiveness of the EU industrial system.

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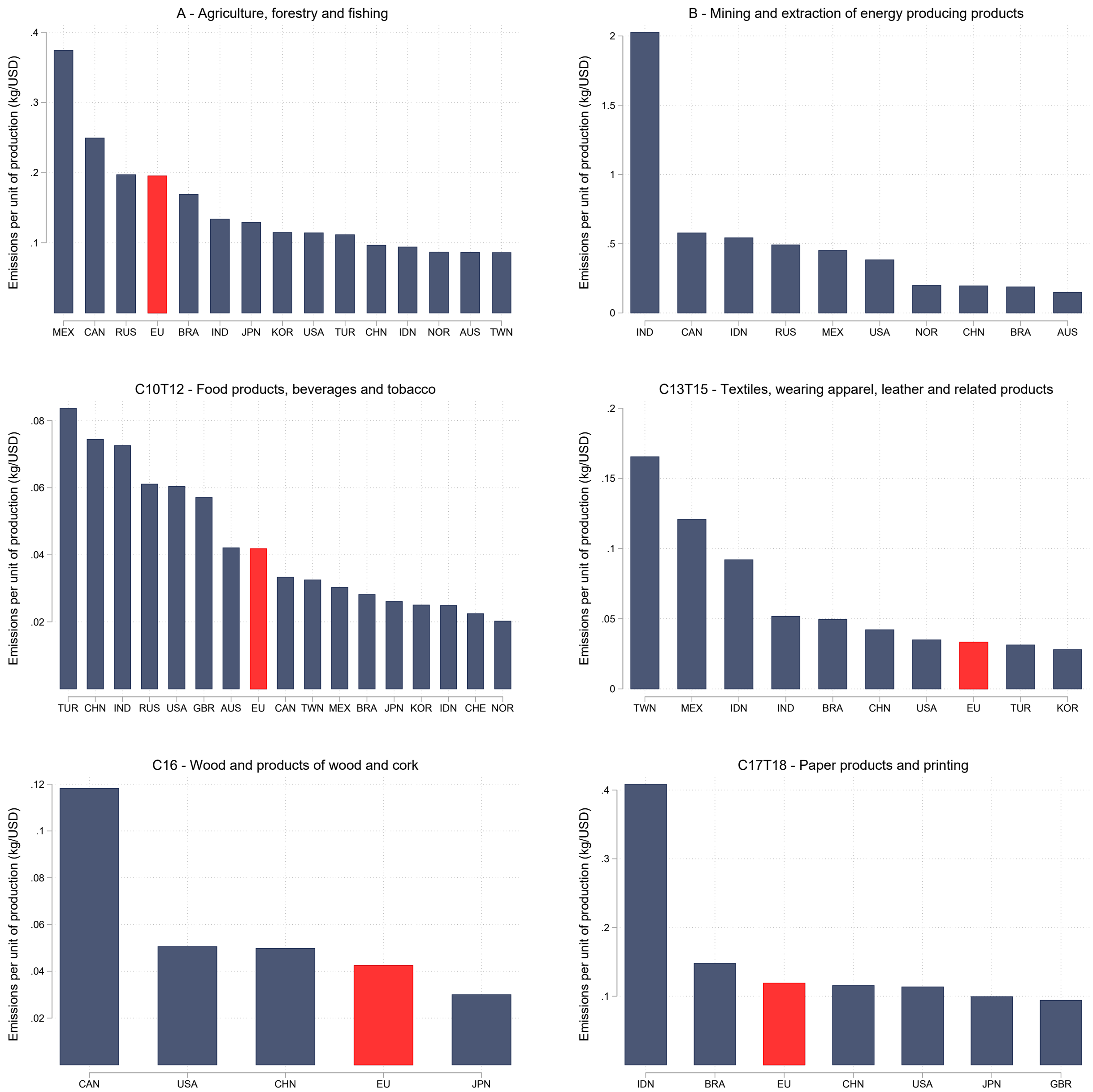
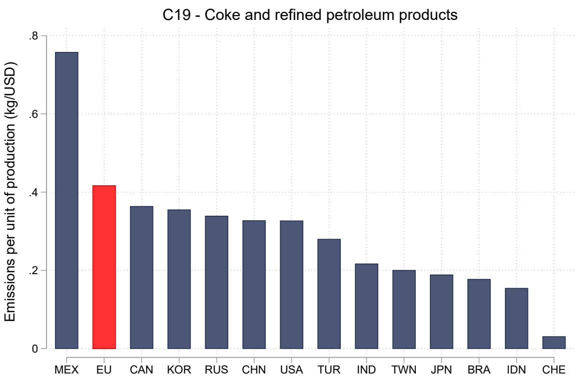
A Stylised Facts

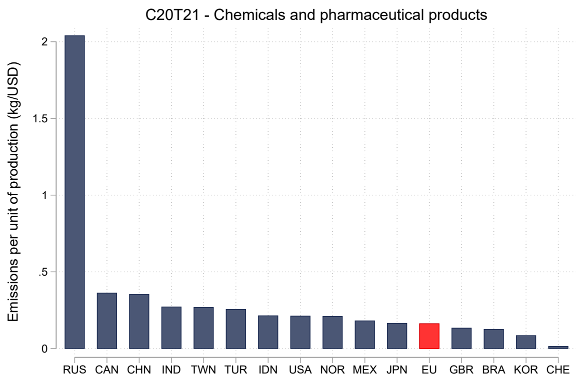
A.1 Ranking of countries by emission intensities; a sector representation

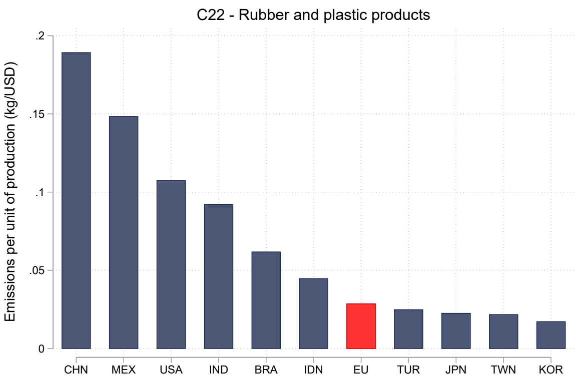
Emission intensities are defined as the emissions per unit worth of US dollar production. They are computed as emissions per sector country in 2016, last year of reported emissions in the WIOD environmental database, over the gross value in US dollar of the production by sector and country.

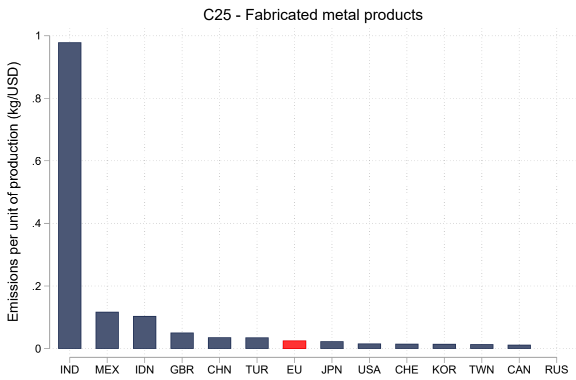
Figure (A1) Ranking of countries by emission intensity for each sector

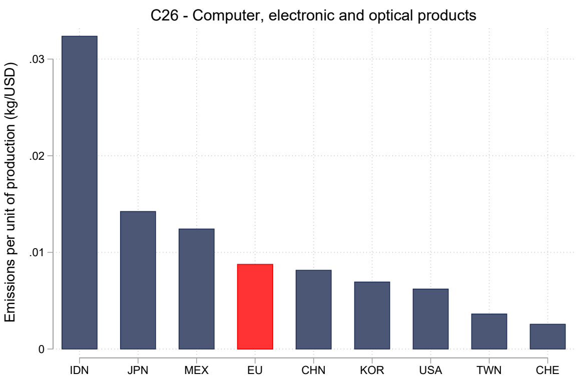


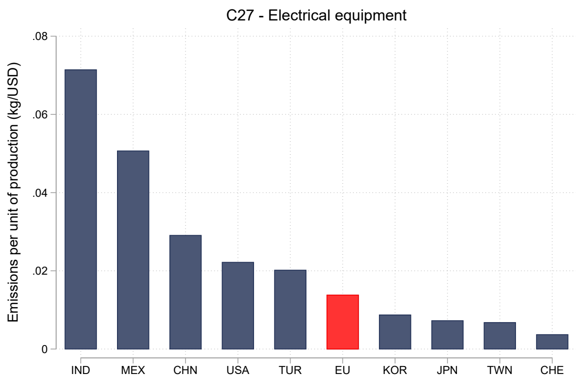

C19 - Coke and refined petroleum products
Emissions per unit of production (kg/USD)
0
.2
.4
.6
.8
MEX EU CAN KOR RUS CHN USA TUR IND TWN JPN BRA IDN CHE

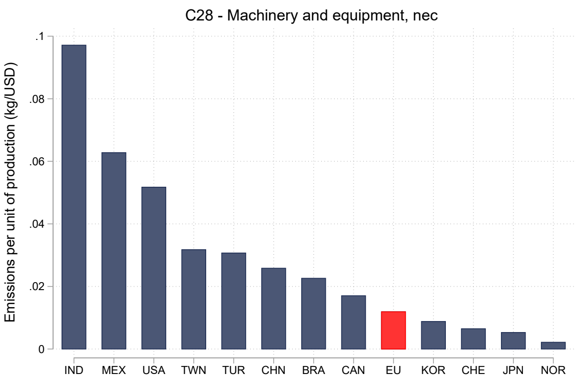

C20T21 - Chemicals and pharmaceutical products
Emissions per unit of production (kg/USD)
0
.5
1
1.5
2
RUS CAN CHN IND TWN TUR IDN USA NOR MEX JPN EU GBR BRA KOR CHE

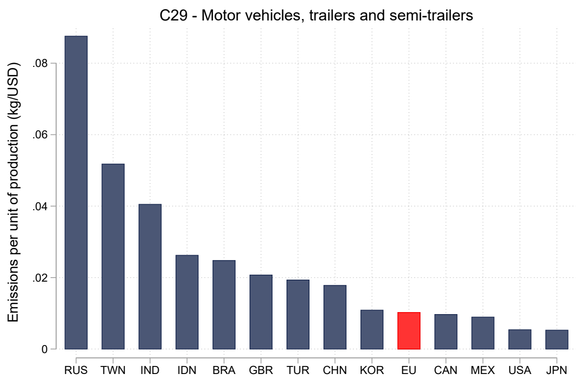

C22 - Rubber and plastic products
Emissions per unit of production (kg/USD)
0
.05
.1
.15
.2
CHN MEX USA IND BRA IDN EU TUR JPN TWN KOR

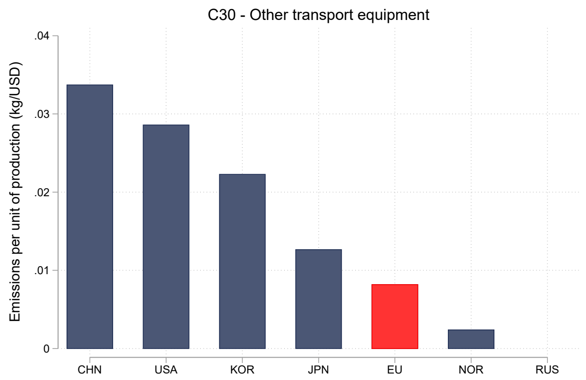

C25 - Fabricated metal products
Emissions per unit of production (kg/USD)
0
.2
.4
.6
.8
1
IND MEX IDN GBR CHN TUR EU JPN USA CHE KOR TWN CAN RUS

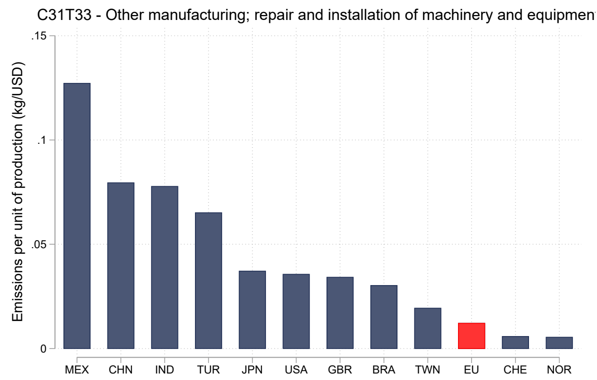

C26 - Computer, electronic and optical products
Emissions per unit of production (kg/USD)
0
.01
.02
.03
IDN JPN MEX EU CHN KOR USA TWN CHE

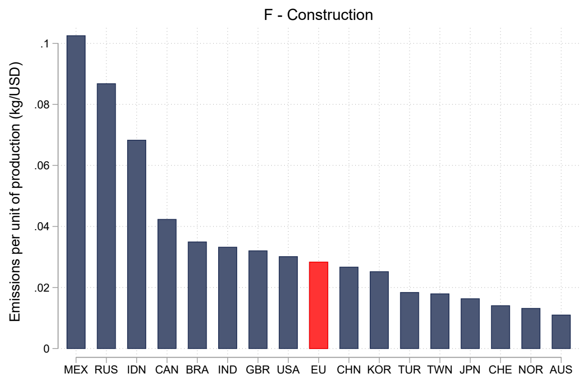

C27 - Electrical equipment
Emissions per unit of production (kg/USD)
0
.02
.04
.06
.08
IND MEX CHN USA TUR EU KOR JPN TWN CHE

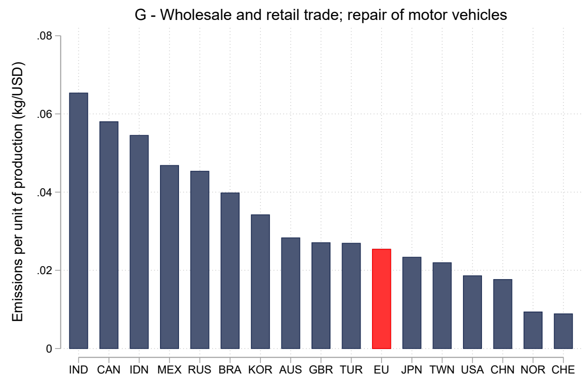

C28 - Machinery and equipment, nec
Emissions per unit of production (kg/USD)
0
.02
.04
.06
.08
.1
IND MEX USA TWN TUR CHN BRA CAN EU KOR CHE JPN NOR

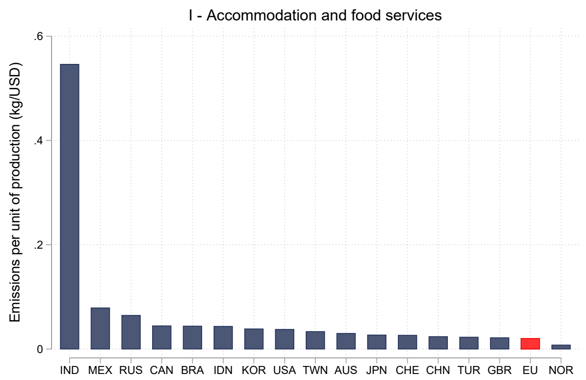

C29 - Motor vehicles, trailers and semi-trailers
Emissions per unit of production (kg/USD)
0
.02
.04
.06
.08
RUS TWN IND IDN BRA GBR TUR CHN KOR EU CAN MEX USA JPN

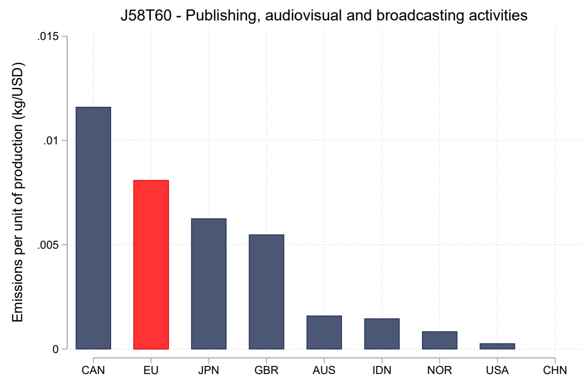

C30 - Other transport equipment
Emissions per unit of production (kg/USD)
0
.01
.02
.03
.04
CHN
USA
KOR
JPN
EU
NOR
RUS

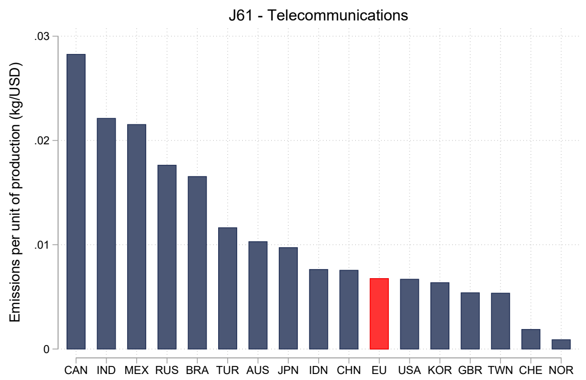

C31T33 - Other manufacturing; repair and installation of machinery and equipmen
Emissions per unit of production (kg/USD)
0
.05
.1
.15
MEX
CHN
IND
TUR
JPN
USA
GBR
BRA
TWN
EU
CHE
NOR

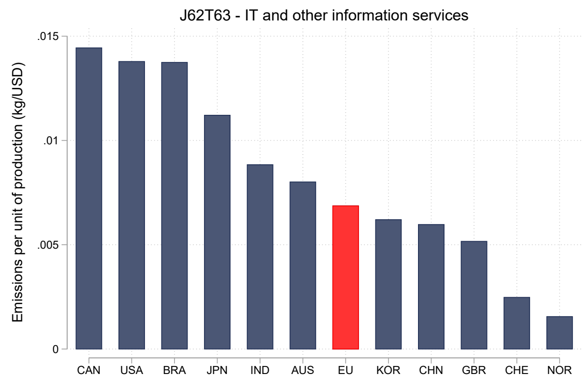

F - Construction
Emissions per unit of production (kg/USD)
0
.02
.04
.06
.08
.1
MEX
RUS
IDN
CAN
BRA
IND
GBR
USA
EU
CHN
KOR
TUR
TWN
JPN
CHE
NOR
AUS

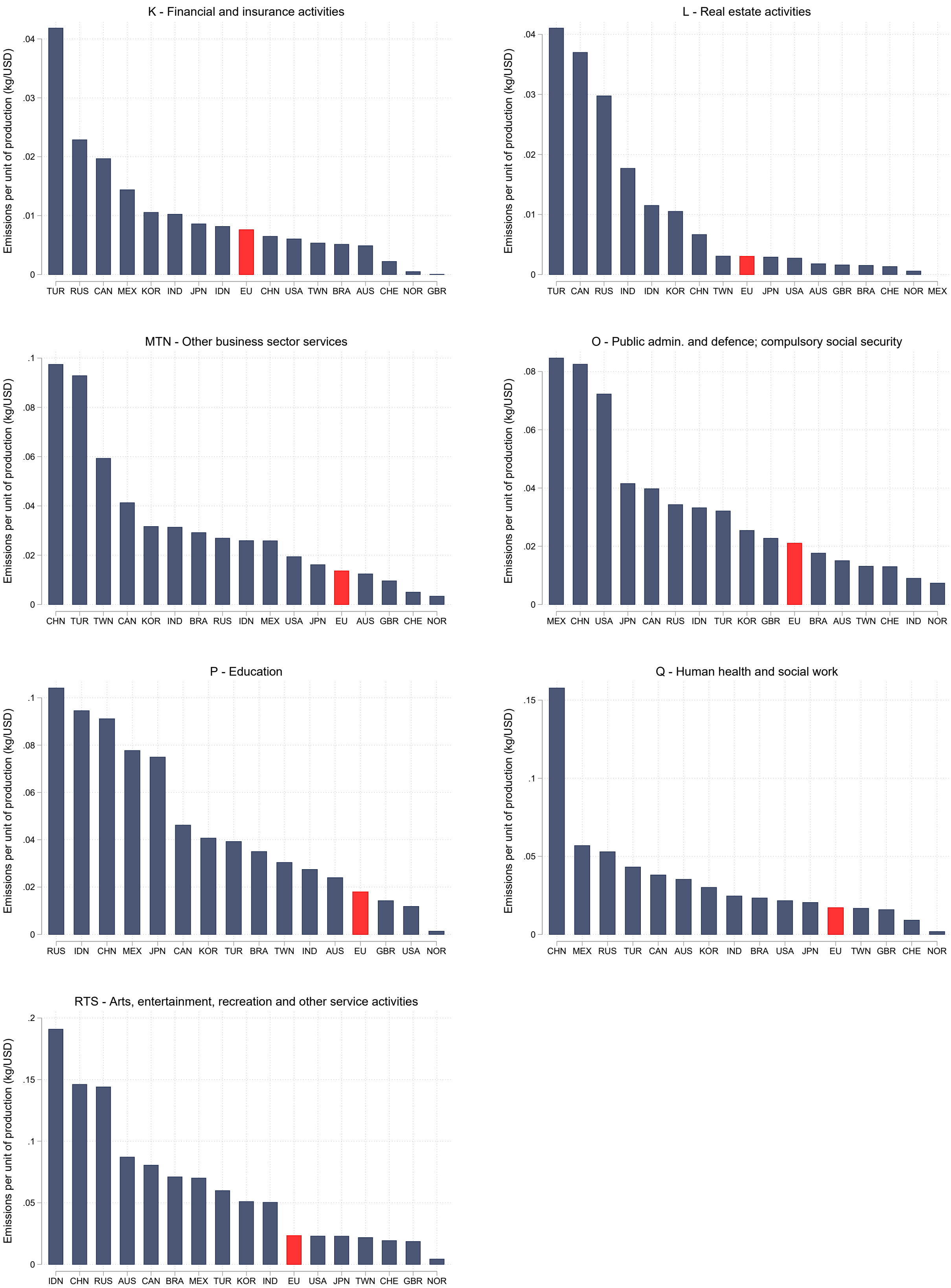

G - Wholesale and retail trade; repair of motor vehicles
Emissions per unit of production (kg/USD)
0
.02
.04
.06
.08
IND
CAN
IDN
MEX
RUS
BRA
KOR
AUS
GBR
TUR
EU
JPN
TWN
USA
CHN
NOR
CHE


I - Accommodation and food services
Emissions per unit of production (kg/USD)
0
.2
.4
.6
IND
MEX
RUS
CAN
BRA
IDN
KOR
USA
TWN
AUS
JPN
CHE
CHN
TUR
GBR
EU
NOR


J58T60 - Publishing, audiovisual and broadcasting activities
Emissions per unit of production (kg/USD)
0
.005
.01
.015
CAN
EU
JPN
GBR
AUS
IDN
NOR
USA
CHN


J61 - Telecommunications
Emissions per unit of production (kg/USD)
0
.01
.02
.03
CAN
IND
MEX
RUS
BRA
TUR
AUS
JPN
IDN
CHN
EU
USA
KOR
GBR
TWN
CHE
NOR


J62T63 - IT and other information services
Emissions per unit of production (kg/USD)
0
.005
.01
.015
CAN
USA
BRA
JPN
IND
AUS
EU
KOR
CHN
GBR
CHE
NOR



K - Financial and insurance activities
Emissions per unit of production (kg/USD)
TUR RUS CAN MEX KOR IND JPN IDN EU CHN USA TWN BRA AUS CHE NOR GBR
L - Real estate activities
Emissions per unit of production (kg/USD)
TUR CAN RUS IND IDN KOR CHN TWN EU JPN USA AUS GBR BRA CHE NOR MEX
MTN - Other business sector services
Emissions per unit of production (kg/USD)
CHN TUR TWN CAN KOR IND BRA RUS IDN MEX USA JPN EU AUS GBR CHE NOR
O - Public admin. and defence; compulsory social security
Emissions per unit of production (kg/USD)
MEX CHN USA JPN CAN RUS IDN TUR KOR GBR EU BRA AUS TWN CHE IND NOR
P - Education
Emissions per unit of production (kg/USD)
RUS IDN CHN MEX JPN CAN KOR TUR BRA TWN IND AUS EU GBR USA NOR
Q - Human health and social work
Emissions per unit of production (kg/USD)
CHN MEX RUS TUR CAN AUS KOR IND BRA USA JPN EU TWN GBR CHE NOR
RTS - Arts, entertainment, recreation and other service activities
Emissions per unit of production (kg/USD)
IDN CHN RUS AUS CAN BRA MEX TUR KOR IND EU USA JPN TWN CHE GBR NOR

Table (A2) Emission intensity rates relative to EU aggregate

ind	AUS	BRA	CAN	CHE	CHN	GBR	IDN	IND	JPN	KOR	MEX	NOR	ROW	RUS	TUR	TWN	USA
Agriculture, forestry & fishing	0.441	0.865	1.276	0.434	0.494	1.008	0.481	0.685	0.660	0.587	1.917	0.444	0.515	1.008	0.570	0.440	0.585
Mining & extraction of energy producing products	0.523	0.659	2.026	0.129	0.683	1.525	1.901	7.103	11.04	18.66	1.581	0.697	0.625	1.722	0.172	26.67	1.343
Food products, beverages & tobacco	1.007	0.673	0.797	0.536	1.780	1.366	0.595	1.736	0.623	0.598	0.724	0.484	1.299	1.461	2.003	0.777	1.445
Textiles, wearing apparel, leather & related products	2.543	1.483	2.252	0.559	1.265	2.537	2.762	1.553	1.437	0.839	3.628	0.273	1.561	2.173	0.940	4.966	1.048
Wood & products of wood & cork	0.550	1.850	2.786	0.252	1.173	1.622	1.780	19.44	0.707	0.466	8.560	0.264	1.321	8.957	0.983	0.819	1.191
Paper products & printing	0.746	1.241	1.457	0.299	0.969	0.789	3.432	1.715	0.833	0.710	1.538	0.310	0.885	1.342	0.807	1.742	0.953
Coke & refined petroleum products	0.719	0.425	0.873	0.0730	0.786	1.735	0.370	0.520	0.452	0.852	1.820	2.547	1.016	0.814	0.671	0.480	0.784
Chemicals & pharmaceutical products	2.261	0.772	2.240	0.0839	2.182	0.823	1.323	1.680	1.016	0.520	1.118	1.297	1.499	12.65	1.579	1.658	1.311
Rubber & plastic products	0.217	2.164	6.259	0.437	6.625	3.467	1.564	3.227	0.786	0.601	5.199	0.986	113.3	1.016	0.869	0.759	3.766
Other non-metallic mineral products	0.744	0.571	0.876	0.602	1.147	0.594	1.788	1.724	1.064	0.633	0.850	0.619	1.047	2.664	2.867	0.702	0.949
Basic metals	1.572	1.863	1.125	0.182	1.445	1.219	1.491	3.012	1.178	1.822	0.656	1.332	1.493	5.849	0.694	1.561	0.949
Fabricated metal products	0.450	1.838	0.455	0.581	1.420	2.044	4.202	40.01	0.901	0.561	4.768	0.187	2.859	0	1.407	0.519	0.613
Computer, electronic & optical products	1.363	1.128	2.046	0.293	0.931	2.029	3.698	5.189	1.626	0.792	1.419	0.0230	1.550	8.819	4.672	0.414	0.709
Electrical equipment	0.870	2.369	1.308	0.267	2.107	2.610	12.23	5.178	0.525	0.632	3.673	0.157	1.914	0	1.462	0.491	1.608
Machinery & equipment, nec	1.156	1.900	1.431	0.545	2.170	2.465	2.413	8.162	0.444	0.740	5.275	0.181	3.467	19.15	2.579	2.669	4.348
Motor vehicles & (semi-)trailers	0.646	2.426	0.946	0.645	1.743	2.027	2.568	3.965	0.515	1.064	0.874	0.291	1.820	8.575	1.891	5.070	0.527
Other transport equipment	0.989	1.968	1.119	0.779	4.125	2.590	0.947	6.795	1.547	2.725	1.759	0.292	3.083	0	6.203	12.01	3.498
Other manufacturing; repair & installation of machinery & equipment	2.488	2.500	2.544	0.478	6.573	2.827	12.00	6.430	3.070	3.080	10.52	0.448	73.47	0.962	5.385	1.600	2.945
Electricity, gas, water supply, sewerage, waste & remediation services	2.109	0.476	1.719	0.0640	4.906	0.397	5.261	6.219	1.396	2.599	4.951	0.128	5.412	4.662	1.543	5.234	3.713
Construction	0.387	1.234	1.495	0.496	0.942	1.131	2.411	1.173	0.576	0.889	3.621	0.464	3.782	3.065	0.649	0.633	1.064
Wholesale & retail trade; repair of motor vehicles	1.116	1.569	2.287	0.350	0.696	1.067	2.149	2.576	0.920	1.348	1.845	0.369	3.498	1.787	1.061	0.865	0.733
Transport & storage	2.360	2.965	4.134	0.356	1.035	1.270	6.860	1.792	1.273	3.259	1.858	1.082	4.539	2.881	0.649	6.731	3.206
Accommodation & food services	1.484	2.177	2.200	1.307	1.179	1.073	2.154	27.10	1.330	1.914	3.912	0.375	4.042	3.201	1.126	1.659	1.866
Publishing, audiovisual & broadcasting activities	0.196	0.0836	1.435	0.577	0	0.678	0.180	0	0.773	2.018	0.393	0.103	1.443	0	19.89	0.246	0.0318
Telecommunications	1.525	2.451	4.187	0.278	1.118	0.799	1.130	3.277	1.441	0.942	3.190	0.132	4.189	2.612	1.723	0.793	0.991
IT & other information services	1.168	2.003	2.104	0.361	0.870	0.752	2.334	1.288	1.634	0.904	1.413	0.227	8.327	0	3.779	1.377	2.009
Financial & insurance activities	0.643	0.675	2.591	0.291	0.853	0.00425	1.075	1.348	1.132	1.389	1.895	0.0638	3.358	3.014	5.512	0.703	0.795
Real estate activities	0.590	0.500	12.23	0.436	2.199	0.526	3.802	5.844	0.958	3.475	0	0.187	6.901	9.836	13.57	1.010	0.899
Other business sector services	0.910	2.142	3.033	0.366	7.160	0.703	1.903	2.303	1.185	2.325	1.898	0.245	10.65	1.976	6.822	4.357	1.424
Public admin. & defence; compulsory social security	0.716	0.838	1.891	0.618	3.927	1.082	1.580	0.427	1.976	1.209	4.028	0.349	9.458	1.632	1.528	0.624	3.440
Education	1.334	1.947	2.569	0.591	5.069	0.792	5.258	1.527	4.167	2.263	4.322	0.0749	3.718	5.791	2.184	1.691	0.657
Human health & social work	2.068	1.367	2.232	0.533	9.253	0.929	4.905	1.442	1.198	1.765	3.335	0.106	6.564	3.103	2.530	0.979	1.266
Arts, entertainment, recreation & other service activities	3.729	3.041	3.448	0.825	6.256	0.795	8.175	2.155	0.979	2.183	2.999	0.183	5.410	6.168	2.564	0.931	0.982

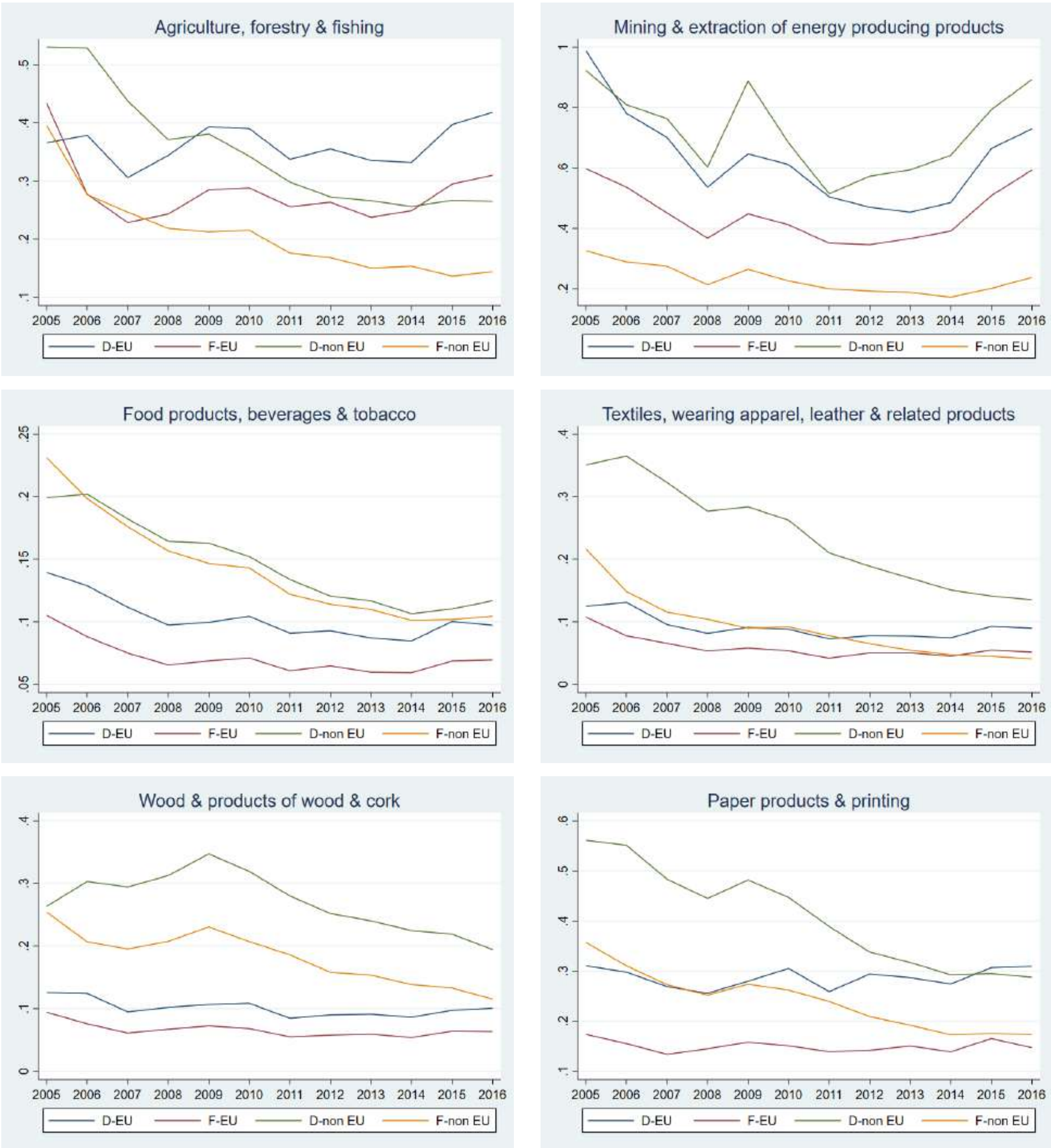
Notes: Sector definitions are from the OECD, STI, analytical AMNE. The table shows emission intensity per unit of output relative to that of the EU in the given sector. A value above unity means the country has a higher emission intensity than the EU.

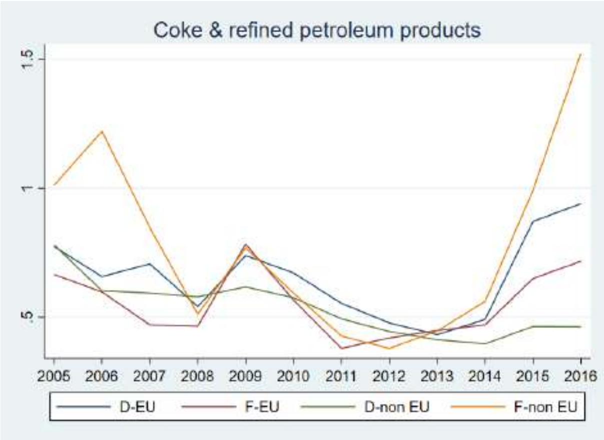
A.2 Shares of emission-intensive inputs on total costs

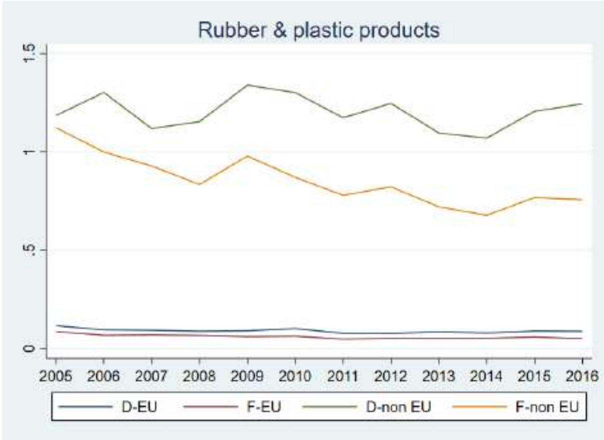
Figure (A2) ETS sectors

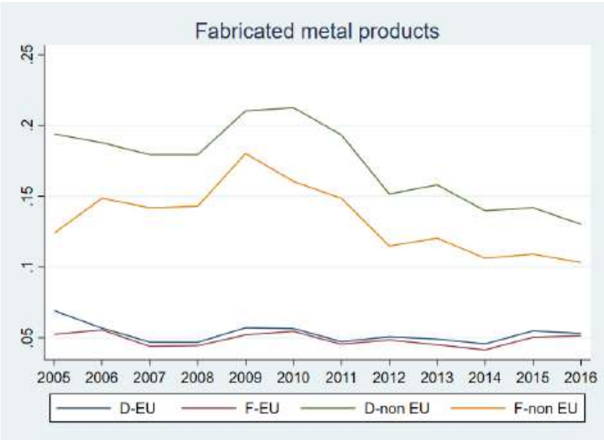
Note: D-EU - Domestic-owned firms in the EU, F-EU - Foreign-owned firms in the EU, D-non EU - Domestic-owned firms outside of the EU, F-non EU: Foreign-owned firms outside of the EU. Source OECD AMNE.

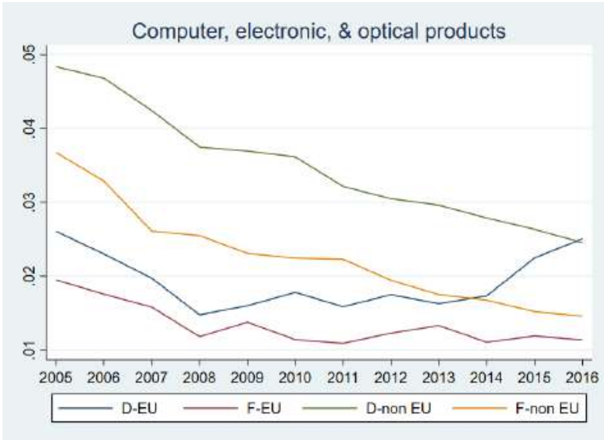
Figure (A3) non-ETS sectors

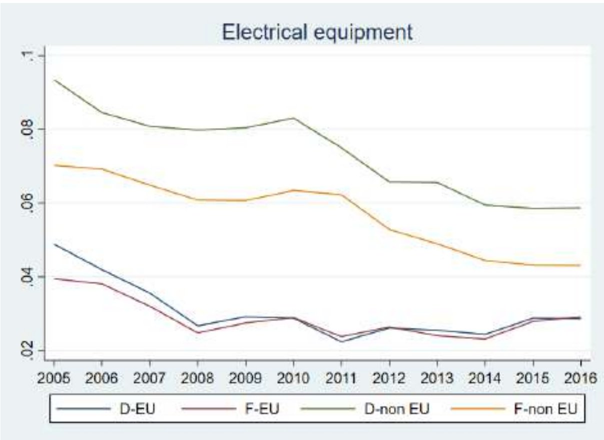


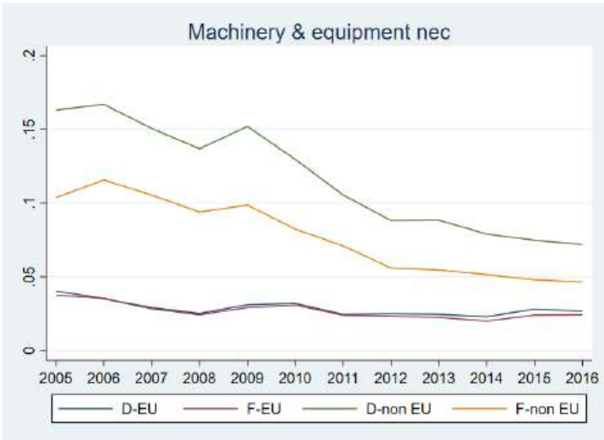

Coke & refined petroleum products
.5
1
1.5
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

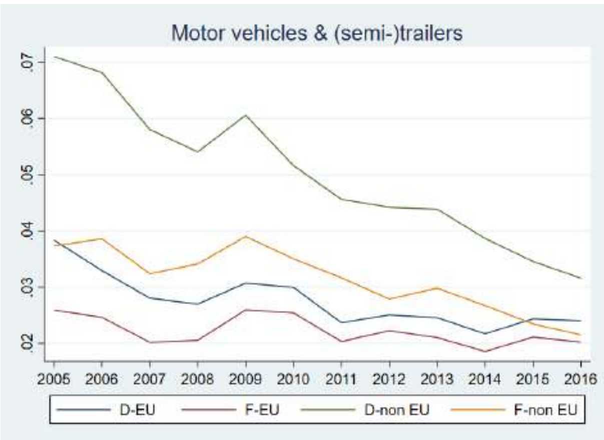

Rubber & plastic products
0
.5
1
1.5
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Fabricated metal products
.05
.1
.15
.2
.25
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

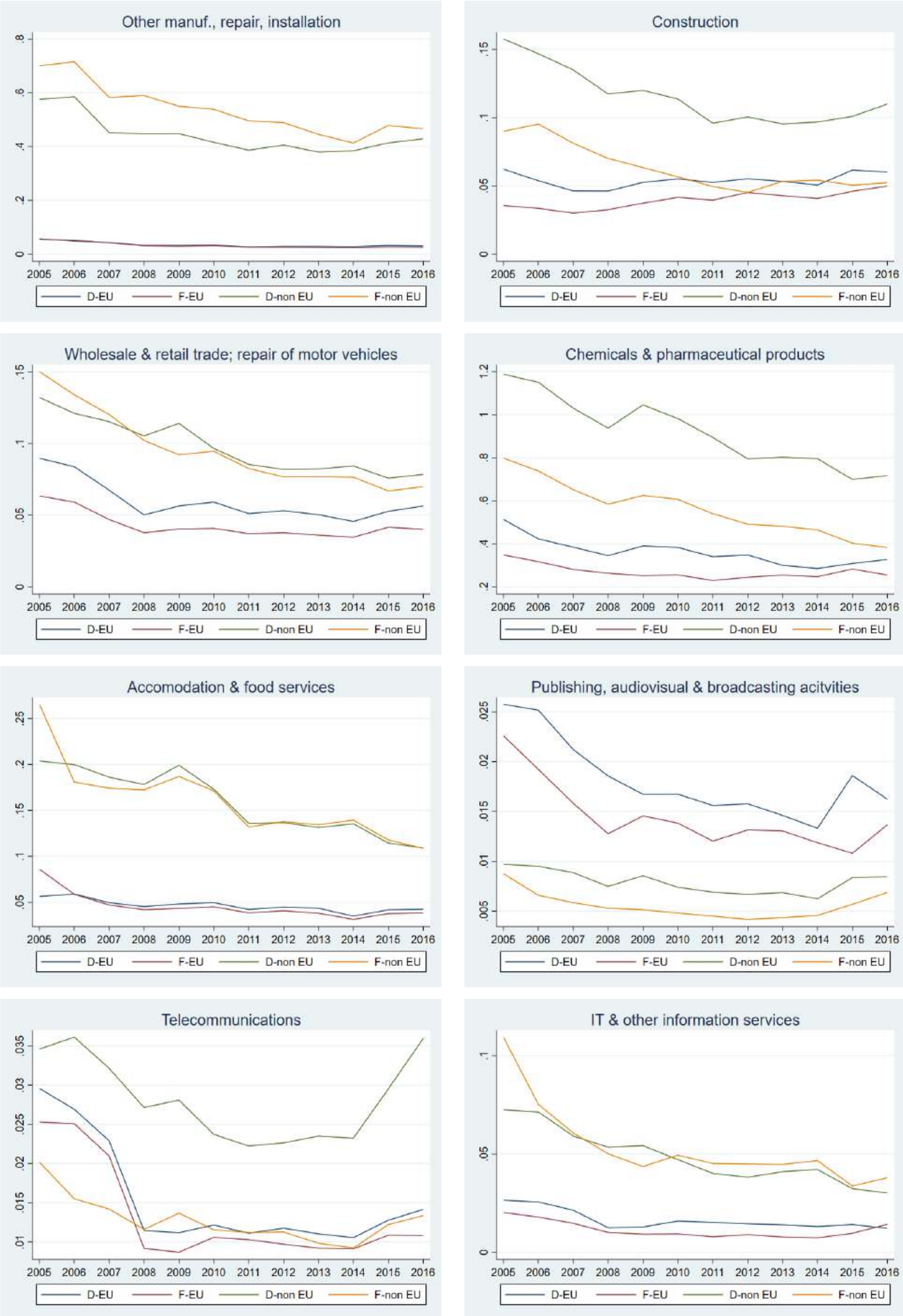

Computer, electronic, & optical products
.01
.02
.03
.04
.05
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

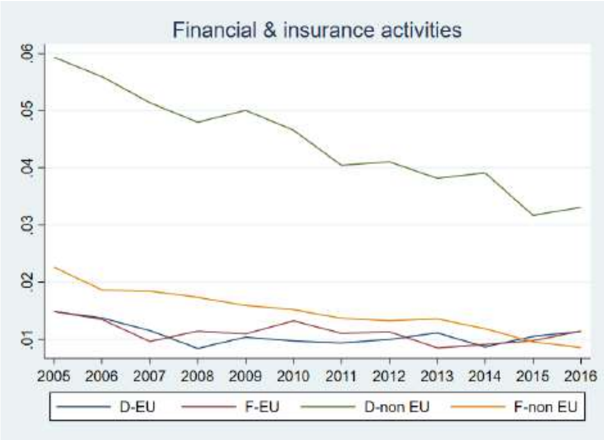

Electrical equipment
.02
.04
.06
.08
.1
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

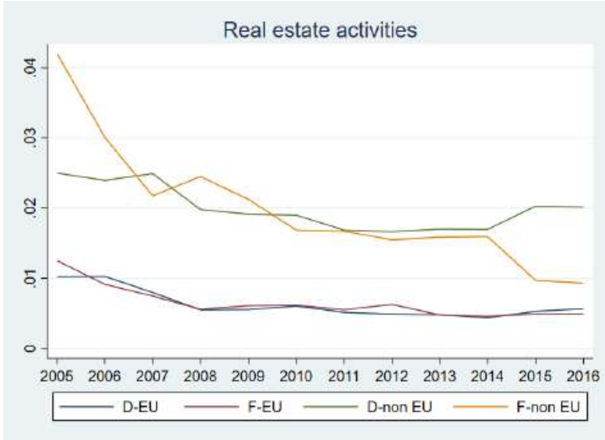

Machinery & equipment nec
0
.05
.1
.15
.2
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

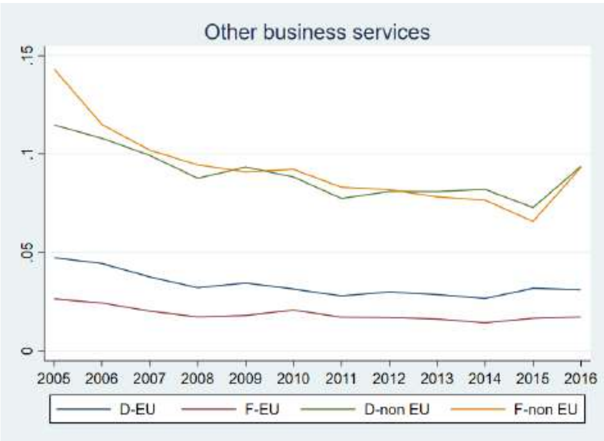

Motor vehicles & (semi-)trailers
.02
.03
.04
.05
.06
.07
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

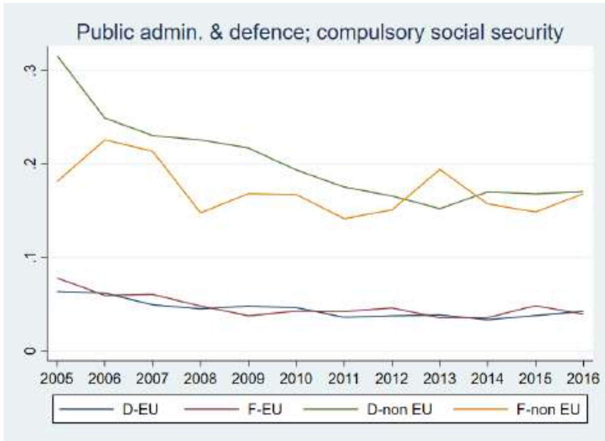

Other transport equipment
.02
.04
.06
.08
.1
.12
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

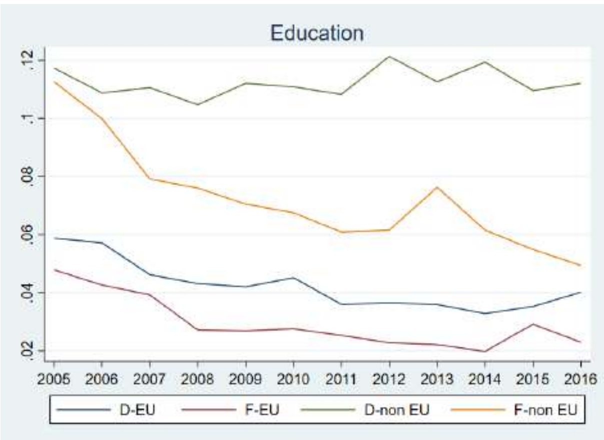

Other manuf., repair, installation
Construction
Wholesale & retail trade; repair of motor vehicles
Chemicals & pharmaceutical products
Accomodation & food services
Publishing, audiovisual & broadcasting acitvities
Telecommunications
IT & other information services
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

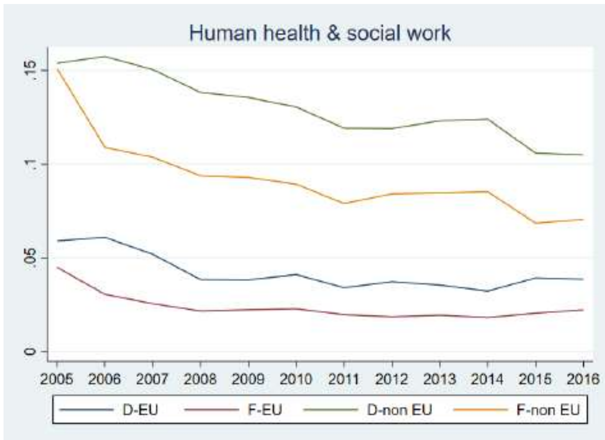

Financial & insurance activities
.06
.05
.04
.03
.02
.01
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

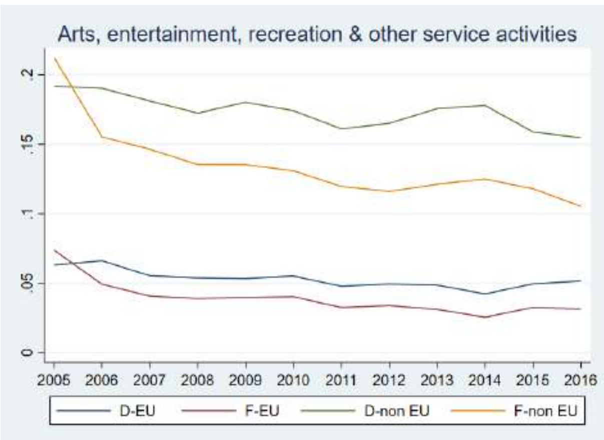

Real estate activities
.04
.03
.02
.01
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Other business services
.15
.1
.05
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Public admin. & defence; compulsory social security
.3
.2
.1
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Education
.12
.1
.08
.06
.04
.02
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Human health & social work
.15
.1
.05
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU


Arts, entertainment, recreation & other service activities
.2
.15
.1
.05
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
D-EU
F-EU
D-non EU
F-non EU

Note: D-EU - Domestic-owned firms in the EU, F-EU - Foreign-owned firms in the EU, D-non EU - Domestic-owned firms outside of the EU, F-non EU: Foreign-owned firms outside of the EU. Source OECD AMNE.

B Empirical Results

B.1 Were there some ETS sectors primarily contributing to Co2 reductions? Sector by sector analysis

Table (A5) Diff in diff in diff estimates of the ETS performance and of carbon leakages -differential dynamics in sector C19 ”Coke and refined petroleum products”

	$\log(em)_t$		Δ $\log(em)_t$	
	(1)	(2)	(3)	(4)
$\log(em)_{t-1}$	0.841***	0.838***	-0.164***	-0.165***
	(0.00368)	(0.00409)	(0.00411)	(0.00413)
Δ $\log(em)_{t-1}$			-0.0268***	-0.0600**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0446***	-0.0778***	-0.000596	-0.000237
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0512**	-0.00496	0.0460*	0.0437*
	(0.0169)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0803***	0.0615	-0.0774**	-0.0615**
	(0.0215)	(0.111)	(0.0242)	(0.0232)
D4: year $\geq$ 2005, ind = C19, cou. $\in$ EU	0.104**	0.218**	0.0776*	
	(0.0316)	(0.0747)	(0.0356)	
D1 X $\log(em)_{t-1}$		0.00558***		
		(0.00167)		
D2 X $\log(em)_{t-1}$		0.00274		
		(0.00903)		
D3 X $\log(em)_{t-1}$		-0.0145		
		(0.0107)		
D4 X $\log(em)_{t-1}$		-0.0196*		
		(0.00917)		
D1 X Δ $\log(em)_{t-1}$				0.0452*
				(0.0225)
D2 X Δ $\log(em)_{t-1}$				0.124*
				(0.0625)
D3 X Δ $\log(em)_{t-1}$				-0.191**
				(0.0714)
D4 X Δ $\log(em)_{t-1}$				-0.0318
				(0.0457)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interction of D1 with a dummy taking on value 1 for regulated industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries.*

Table (A6) Diff in diff in diff estimates of the ETS performance and of carbon leakages - differential dynamics in sector C23 "Other non-metallic mineral products"

	$\log(\text{em})_t$		Δ $\log(\text{em})_t$	
	(1)	(2)	(3)	(4)
$\log(\text{em})_{t-1}$	0.841***	0.837***	-0.164***	-0.165***
	(0.00368)	(0.00406)	(0.00411)	(0.00413)
Δ $\log(\text{em})_{t-1}$			-0.0263***	-0.0600**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0446***	-0.0791***	-0.000657	-0.0000810
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0513**	-0.00491	0.0460*	0.0437*
	(0.0170)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0601**	0.175	-0.0627**	-0.0611**
	(0.0215)	(0.105)	(0.0243)	(0.0232)
D4: year $\geq$ 2005, ind = C23, cou. $\in$ EU	-0.00162	-0.0762	0.000976	
	(0.0310)	(0.123)	(0.0349)	
D1 X $\log(\text{em})_{t-1}$		0.00572***		
		(0.00167)		
D2 X $\log(\text{em})_{t-1}$		0.00269		
		(0.00903)		
D3 X $\log(\text{em})_{t-1}$		-0.0263**		
		(0.00999)		
D4 X $\log(\text{em})_{t-1}$		0.00912		
		(0.0149)		
D1 X Δ $\log(\text{em})_{t-1}$				0.0452*
				(0.0225)
D2 X Δ $\log(\text{em})_{t-1}$				0.124*
				(0.0625)
D3 X Δ $\log(\text{em})_{t-1}$				-0.224***
				(0.0661)
D4 X Δ $\log(\text{em})_{t-1}$				0.267**
				(0.102)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interction of D1 with a dummy taking on value 1 for regulated industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries.*

Table (A7) Diff in diff in diff estimates of the ETS performance and of carbon leakages - differential dynamics in sector C24 "Basic metals"

	$\log(\text{em})_t$		$\Delta\ \log(\text{em})_t$	
	(1)	(2)	(3)	(4)
$\log(\text{em})_{t-1}$	0.841***	0.837***	-0.164***	-0.165***
	(0.00368)	(0.00406)	(0.00411)	(0.00413)
$\Delta\ \log(\text{em})_{t-1}$			-0.0263***	-0.0600**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0447***	-0.0790***	-0.000676	-0.000200
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0513**	-0.00495	0.0460*	0.0437*
	(0.0169)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0512*	0.205	-0.0523*	-0.0623**
	(0.0215)	(0.108)	(0.0242)	(0.0232)
D4: year $\geq$ 2005, ind = C24, cou. $\in$ EU	-0.0455	-0.0994	-0.0509	
	(0.0310)	(0.0817)	(0.0349)	
D1 X $\log(\text{em})_{t-1}$		0.00570***		
		(0.00167)		
D2 X $\log(\text{em})_{t-1}$		0.00270		
		(0.00903)		
D3 X $\log(\text{em})_{t-1}$		-0.0282**		
		(0.0102)		
D4 X $\log(\text{em})_{t-1}$		0.00383		
		(0.0102)		
D1 X $\Delta\ \log(\text{em})_{t-1}$				0.0450*
				(0.0225)
D2 X $\Delta\ \log(\text{em})_{t-1}$				0.124*
				(0.0625)
D3 X $\Delta\ \log(\text{em})_{t-1}$				-0.190**
				(0.0671)
D4 X $\Delta\ \log(\text{em})_{t-1}$				-0.0838
				(0.0524)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interction of D1 with a dummy taking on value 1 for regulated industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries.*

Table (A8) Diff in diff in diff estimates of the ETS performance and of carbon leakages - differential dynamics in sector DTE "Electricity, gas, water supply, sewerage, waste and remediation services"

	$\log(\text{em})_t$		$\Delta \log(\text{em})_t$	
	(1)	(2)	(3)	(4)
$\log(\text{em})_{t-1}$	0.841***	0.837***	-0.164***	-0.165***
	(0.00368)	(0.00406)	(0.00411)	(0.00413)
$\Delta \log(\text{em})_{t-1}$			-0.0265***	-0.0602**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0446***	-0.0787***	-0.000644	-0.000191
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0513**	-0.00488	0.0460*	0.0437*
	(0.0169)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0518*	0.188	-0.0556*	-0.0608**
	(0.0215)	(0.105)	(0.0243)	(0.0232)
D4: year $\geq$ 2005, ind = DTE, cou. $\in$ EU	-0.0427	-0.455*	-0.0341	
	(0.0310)	(0.186)	(0.0349)	
D1 X $\log(\text{em})_{t-1}$		0.00569***		
		(0.00167)		
D2 X $\log(\text{em})_{t-1}$		0.00270		
		(0.00903)		
D3 X $\log(\text{em})_{t-1}$		-0.0279**		
		(0.0100)		
D4 X $\log(\text{em})_{t-1}$		0.0464*		
		(0.0189)		
D1 X $\Delta \log(\text{em})_{t-1}$				0.0454*
				(0.0225)
D2 X $\Delta \log(\text{em})_{t-1}$				0.124*
				(0.0625)
D3 X $\Delta \log(\text{em})_{t-1}$				-0.216**
				(0.0660)
D4 X $\Delta \log(\text{em})_{t-1}$				0.178
				(0.120)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interaction of D1 with a dummy taking on value 1 for regulated industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries.*

Table (A9) Diff in diff in diff estimates of the ETS performance and of carbon leakages -differential dynamics in sector H "Transportation and storage"

	$\log(\text{em})_t$		$\Delta\ \log(\text{em})_t$	
	(1)	(2)	(3)	(4)
$\log(\text{em})_{t-1}$	0.841***	0.837***	-0.164***	-0.165***
	(0.00368)	(0.00405)	(0.00411)	(0.00413)
$\Delta\ \log(\text{em})_{t-1}$			-0.0263***	-0.0600**
			(0.00706)	(0.0211)
D1: year $\geq$ 2005	-0.0446***	-0.0792***	-0.000662	-0.000273
	(0.00964)	(0.0140)	(0.00976)	(0.00976)
D2: year $\geq$ 2005, ind $\in$ ETS	0.0513**	-0.00491	0.0460*	0.0437*
	(0.0170)	(0.0984)	(0.0191)	(0.0191)
D3: year $\geq$ 2005, ind $\in$ ETS, cou. $\in$ EU	-0.0583**	0.171	-0.0644**	-0.0619**
	(0.0215)	(0.105)	(0.0243)	(0.0232)
D4: year $\geq$ 2005, ind = H, cou. $\in$ EU	-0.0103	-0.0864	0.00919	
	(0.0310)	(0.185)	(0.0349)	
D1 X $\log(\text{em})_{t-1}$		0.00573***		
		(0.00167)		
D2 X $\log(\text{em})_{t-1}$		0.00269		
		(0.00903)		
D3 X $\log(\text{em})_{t-1}$		-0.0262**		
		(0.00997)		
D4 X $\log(\text{em})_{t-1}$		0.0108		
		(0.0202)		
D1 X $\Delta\ \log(\text{em})_{t-1}$				0.0451*
				(0.0225)
D2 X $\Delta\ \log(\text{em})_{t-1}$				0.124*
				(0.0625)
D3 X $\Delta\ \log(\text{em})_{t-1}$				-0.214**
				(0.0662)
D4 X $\Delta\ \log(\text{em})_{t-1}$				0.0544
				(0.0850)
Country-Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R-squared	0.725	0.725	0.109	0.110
Observations	23141	23141	21680	21680
Number of id	1456	1456	1453	1453

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the logarithm of t-CO2 equivalent. D1 is a dummy taking on the value 1 from 2005 onward, D2 is the interaction of D1 with a dummy taking on value 1 for regulated industries, D3 is the interaction of D2 with a dummy taking on value 1 for EU countries.*

B.2 Carbon leakages and anti-competitive effects - log difference specification

Table (A10) Sectoral output growth in ETS industries by location and ownership and ETS regulation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			input share domestic		input share foreign		pshare input domestic		pshare input foreign	
	emissions / gross output	inputs / gross output	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS
non-EU-D	-0.000347	-0.00279	0.147	0.0209*	-0.0121	-0.0883***	-0.0351	-0.000709	-0.0148	0.0121
	(0.000441)	(0.00462)	(0.144)	(0.0126)	(0.297)	(0.0287)	(0.0542)	(0.00379)	(0.112)	(0.00966)
non-EU-F	-0.0000811	0.00397	0.0222	0.00958	-0.412**	0.0227	0.00320	-0.00164	0.161**	-0.0158
	(0.000182)	(0.00331)	(0.0672)	(0.00737)	(0.195)	(0.0397)	(0.0205)	(0.00189)	(0.0645)	(0.0118)
EU-D	-0.000263*	0.00175	0.00857	0.0204	-0.0395***	0.0639	-0.0111***	-0.0136**	0.0104***	0.0100
	(0.000148)	(0.00281)	(0.00716)	(0.0168)	(0.0101)	(0.0416)	(0.00237)	(0.00571)	(0.00337)	(0.00858)
EU-F	-0.00207***	-0.00806***	0.0145***	-0.0111	0.0212	-0.0489*	-0.00583***	0.00664*	-0.0165**	0.0680***
	(0.000247)	(0.00252)	(0.00518)	(0.0100)	(0.0202)	(0.0264)	(0.00151)	(0.00359)	(0.00725)	(0.0123)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Number of observations 3,397. Number of id 434. The dependent variable is the delta logarithm of sectoral gross output in industries whose emissions are regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends.*

Table (A11) Sectoral output growth in *the rest of the economy* by location and ownership and the nexus

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			input share domestic		input share foreign		pshare input domestic		pshare input foreign	
	emissions / gross output	inputs / gross output	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS	EU_ ETS	nonEU_ ETS
non-EU-D	-0.000365	0.00247	0.113	-0.00790	-0.102	-0.0175	-0.0753	0.000343	0.0152	0.00624
	(0.000789)	(0.00285)	(0.126)	(0.00737)	(0.180)	(0.0318)	(0.0559)	(0.00170)	(0.0808)	(0.00937)
non-EU-F	-0.000760	0.000408	-0.0245	0.0167***	-0.483***	-0.00593	-0.0446*	-0.00286*	0.206***	-0.0123
	(0.000757)	(0.00201)	(0.0629)	(0.00620)	(0.0963)	(0.0282)	(0.0252)	(0.00168)	(0.0410)	(0.00910)
EU-D	-0.00277	-0.00196	-0.00602	0.0560***	0.0132	-0.0445	-0.00303**	-0.00523	0.00508	0.00893
	(0.00192)	(0.00148)	(0.00512)	(0.0183)	(0.0113)	(0.0504)	(0.00143)	(0.00602)	(0.00383)	(0.0131)
EU-F	-0.00879***	0.000969	0.00288	0.0392***	0.00563	-0.0775***	-0.00573***	-0.00172	-0.000983	0.0140**
	(0.00214)	(0.00115)	(0.00515)	(0.00989)	(0.0124)	(0.0186)	(0.00158)	(0.00333)	(0.00388)	(0.00695)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Number of observations 19,612. Number of id 2,516. The dependent variable is the delta logarithm of sectoral gross output in industries not regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends.*

B.3 Testing for the effects of the ETS reform in phase 3

Table (A12) Gross output of ETS industries by location and ownership and the ETS regulation - interaction with Phase3 time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	emission / output	phase3 emission / output	inputs / output	sh_inp_D _EU_ ETS	sh_inp_D_ nonEU_ ETS	sh_inp_F_ EU_ ETS	sh_inp_F_ nonEU_ ETS	psh_inp_D_ EU_ ETS	psh_inp_D_ nonEU_ ETS	psh_inp_F_ EU_ ETS	psh_inp_F_ nonEU_ ETS
non-EU-D	-0.00129***	0.000150	0.000427	0.0169	0.0125	0.0231	-0.0335	-0.000139	-0.00597*	-0.0116	0.00246
	(0.000361)	(0.000154)	(0.00379)	(0.118)	(0.0103)	(0.243)	(0.0235)	(0.0446)	(0.00317)	(0.0913)	(0.00791)
non-EU-F	-0.000240	-0.0000505	0.000994	0.0655	0.00463	-0.503***	0.0196	0.0145	-0.00142	0.0315	-0.0171*
	(0.000149)	(0.0000711)	(0.00272)	(0.0551)	(0.00606)	(0.160)	(0.0325)	(0.0168)	(0.00160)	(0.0527)	(0.00971)
EU-D	-0.00130***	0.000340***	0.00573**	0.00809	0.0458***	-0.0541***	0.0159	0.00112	-0.00383	-0.00662**	-0.00849
	(0.000217)	(0.000106)	(0.00237)	(0.00586)	(0.0138)	(0.00825)	(0.0340)	(0.00195)	(0.00467)	(0.00276)	(0.00702)
EU-F	-0.00189***	-0.000207**	0.00209	0.00808*	0.00192	-0.0172	0.0296	-0.00482***	-0.000836	-0.0101*	0.0525***
	(0.000213)	(0.0000959)	(0.00207)	(0.00425)	(0.00821)	(0.0165)	(0.0216)	(0.00124)	(0.00294)	(0.00593)	(0.0101)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the delta logarithm of sectoral gross output in industries whose emissions are regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends.*

Table (A13) Sectoral output growth in ETS industries by location and ownership and ETS regulation - interaction with Phase3 time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	emission / output	phase3 emission / output	inputs / output	sh_inp_D _EU_ ETS	sh_inp_D_ nonEU_ ETS	sh_inp_F_ EU_ ETS	sh_inp_F_ nonEU_ ETS	psh_inp_D_ EU_ ETS	psh_inp_D_ nonEU_ ETS	psh_inp_F_ EU_ ETS	psh_inp_F_ nonEU_ ETS
non-EU-D	-0.000361	0.0000993	-0.00260	0.145	0.0216*	-0.0173	-0.0889***	-0.0391	-0.000714	-0.0141	0.0119
	(0.000439)	(0.000187)	(0.00460)	(0.144)	(0.0125)	(0.295)	(0.0286)	(0.0542)	(0.00385)	(0.111)	(0.00961)
non-EU-F	-0.0000812	0.0000850	0.00429	0.0238	0.00885	-0.407**	0.0231	0.00211	-0.00132	0.160**	-0.0173
	(0.000181)	(0.0000864)	(0.00330)	(0.0669)	(0.00736)	(0.194)	(0.0394)	(0.0204)	(0.00194)	(0.0641)	(0.0118)
EU-D	-0.00110***	0.000484***	0.00485*	0.00693	0.0219	-0.0425***	0.0535	-0.00956***	-0.0120**	0.0110***	0.0109
	(0.000263)	(0.000128)	(0.00288)	(0.00712)	(0.0167)	(0.0100)	(0.0413)	(0.00237)	(0.00568)	(0.00335)	(0.00853)
EU-F	-0.00169***	-0.000534***	-0.00913***	0.0166***	-0.0124	0.0204	-0.0408	-0.00695***	0.00577	-0.0159**	0.0671***
	(0.000259)	(0.000117)	(0.00251)	(0.00516)	(0.00998)	(0.0201)	(0.0262)	(0.00151)	(0.00357)	(0.00721)	(0.0123)

*Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is the delta logarithm of sectoral gross output in industries whose emissions are regulated by the ETS. The specification includes ID (e.g. country-sector-ownership) fixed effects, year fixed effects, industry trends and country trends.*

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