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Carbon-motivated border tax adjustment: a proposal for the EU

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Abstract: The analysis focuses on carbon-motivated border tax adjustment (CBTA). CBTA are tariffs applied to imports designed to avoid drawbacks of emission reduction policies when only one or few regions (the abating regions) implement them. Through CBTA the abating regions level out different treatment applied to domestic and imported products. In this paper we focus on CBTA metric. Through a multi-region and multi-sector analysis we compute and compare two possible CBTA systems that the European Union could implement to complement a hypothetical carbon tax applied to domestic products. In one system, tariffs are computed based on the emissions generated abroad to produce the goods imported by the European Union. In the second system, tariffs are based on the emissions that the European Union would have generated to produce domestically the same products. Results at country and sector level contribute to better understand the effects of this instrument and to add information to the political debate on it. Moreover, an important contribution of this analysis is that we explore methodological issues that arise from the use of multi-region and multi-sector models to compute different CBTA metrics.

JEL Codes: C67, D57, H23, Q56.

Keywords: Carbon-motivated border tax adjustmen, European Union, Embodied emissions, Avoided emissions, WIOD database.

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1. Introduction

The threat of climate change caused by air emissions is a global problem that requires global instruments to be addressed. The absence of a commitment to implement tools at a global scale is one of the major difficulties to reach an international agreement after Kyoto, and one of the main limits of the policies implemented so far.

In this context, there is currently an important debate regarding carbon-motivated border tax adjustment (CBTA). CBTA is a trade instrument that consists in tariffs on imported products applied by countries that are implementing local policies to reduce emissions (hereafter abating regions). CBTA is designed to remedy the main drawback of unilateral emission control: emission reduction policies applied only locally create a gap between the price of domestic and foreign products that compete in the same market. To level out different treatments to domestic and foreign goods, or using a recurring expression to “level the carbon playing field” (Houser et al. 2008, Krugman 2009), CBTA tariffs would be imposed on products imported from all countries that are not applying the carbon control policy (hereafter non-abating regions). This would compensate for the loss of competitiveness that a carbon tax may imply for domestic producers, and it would avoid possible emission leakage involved in unilateral emission reduction policies (Lockwood and Whalley 2010, Horn and Sapir 2013).[1]

The viability of this tool has already reached the political agenda of countries like United States (USA) and the European Union (EU) (Mattoo et al., 2009, Kuik, 2010). In 2009 the USA government proposed to implement an emission trade mechanism, the American Clean Energy and Security Act (American House of Representative, 2009).[2] Although finally the act was not approved, the proposal included the border adjustment as a competitiveness measure to ensure the equal distribution of costs in the absence of an international agreement limiting emissions. In the same year also the EU expressed worries about possible carbon leakage caused by the European Emission Trading Scheme (ETS). In the revised ETS directive (European Parliament and Council, 2009), the EU evaluated the inclusion of importers in the Community scheme. Also international trade authorities such as the World Trade Organization (WTO) have already reckoned the relevance of CBTA (see UNEP and WTO 2009, and Hillman 2013).

However, CBTA has not been implemented so far. Its application might be difficult due to the several issues that it arises. These issues are, for example, CBTA

[1] To better justify CBTA, Horn and Sapir (2013) refer to international externalities that arise when countries combat emissions unilaterally. Indeed, countries implementing unilateral climate policy face the full costs of their abatement efforts, receiving only part of the benefits that are spread across the world. As a result, they will typically choose sub-optimal climate policies exposing each other to more climate damage than would be internationally efficient, that is, exposing each other to international externalities.
[2] The American Clean Energy and Security Act was a US energy bill that, if approved by the Senate too, would have established an emission trading mechanism similar to the European Union Emission Trading Scheme.

compatibility with the international legal framework established by the WTO, what countries and what products should be involved, or how non-abating regions would respond to such a tax on their imports.

In particular, in this paper we focus on the so-called CBTA metric or, in other terms, what criteria should be applied to compute emissions related to imported products. Indeed, tariffs can be computed through different methods. One method is to compute the tariffs based on the emissions contained in each imported product, taking into account the technology and resources actually used to produce them. We call this method CBTA on embodied emissions. Alternatively, the tariff could be based on the emissions embodied in the same good produced by the abating region, as if the foreign product would have been produced with the technology available domestically. We call this method CBTA on avoided emissions.

The debate revolves around three implications of these different metrics. The first one is its compatibility with the WTO legal framework. The WTO regulation detailed by GATT (1994) permits import duties not in excess to those applied to like domestic products (Mattoo et al. 2009, Hillman 2013). Therefore, tariffs calculated on avoided emissions are more justifiable as a trade policy. The second dimension is the political feasibility in terms of practical implementation. Also in this case CBTA on avoided emissions is easier to be implemented because it implies no discrimination among exporting countries. Moreover it requires less information on the emission embodied in imported products. The third dimension is the CBTA environmental effectiveness. While CBTA on embodied emissions is based on the actual emission content of each product, CBTA on avoided emissions might be less effective as an environmental policy, since it would not give any incentive for exporting countries to implement more environmentally-friendly technologies.

Focusing on the different methods of designing a CBTA system, in this paper we analyze to what extent the two CBTA metrics would affect differently different products imported from different countries. In particular, we assume a unilateral carbon tax implemented in the EU, and we simulate a corresponding CBTA system to show the different tax rates that each metric implies. We use a multi-region and multi-sector analysis to know for which countries and products the method used is critical. The results of this paper might contribute to the political debate by adding information on the different effects for different products and countries.

There is an already vast literature on CBTA (see Ghosh et al. 2012 for a survey). Some papers analyze and compare different metrics of computing CBTA tariffs, although they do not consider all the connections among sectors and countries that characterize the production processes nowadays and that determine emissions too. Mathiesen and Maestad (2004), Kuik and Hofkes (2009), and Lin and Li (2011) consider only direct emissions of different sectors through sectors' emission intensity. Alternatively, Burniaux et al. (2013) consider the sum of direct emissions and emissions embodied in sectors' electricity use.

Instead, other papers takes into account countries' and sectors' interconnections to determine CBTA rates but they do not offer a comparison between different policy designs. Atkinson et al. (2011) focus on emissions embodied in domestic production and emissions embodied in consumption. Dissou and Eyland (2011) analyze different CBTA recycling methods. Ghosh et al. (2012) focus on efficiency and distributional consequences of CBTA calculated only on CO_2 emissions or CBTA calculated on different greenhouse gases (GHG). Finally, Schenker et al. (2012) analyse CBTA in terms of output variation, welfare effect, carbon leakage, and trade composition.

Up to now, only three papers - Mattoo et al. (2009), Böhringer et al. (2012), and Elliott et al. (2012) - consider both issues together: they compare different CBTA designs taking into account all inter-country inter-sector interdependencies.

In particular, Mattoo et al. (2009) assess the different impact of CBTA based on non-abating regions' emissions and CBTA based on abating region's emissions. They consider several non-abating regions,[3] assuming unilateral emissions reductions of 17% by 2020 in high income countries (EU, USA, Japan, and other United Nations Framework Convention on Climate Change (UNFCCC) Annex-I countries). They use a computable general equilibrium model based on 2004 data from the Global Trade Analysis Project (GTAP). The main finding is that CBTA on non-abating regions' emissions implies average tariffs for India and China of over 20% and depresses manufacturing exports between 16 and 21%. Moreover, CBTA on abating region's emissions addresses the competitiveness problems without so many damages for exporting countries.

Böhringer et al. (2012) compute the efficiency impact of different CBTA designs, analyzing three different regulating coalitions: Europe, UNFCCC Annex-I regions except for Russia, and a broad coalition that includes China. They simulate a unilateral cap at 80% of the abating regions' emissions. CBTA varies among three dimensions: embodied carbon coverage (direct, direct and electricity-related, or total emissions), sector coverage (energy-intensive trade-exposed goods, or all goods), tariff rate differentiation (country- and sector-specific, or sector-specific tariffs). Using 2004 GTAP data, they find that systems more likely to comply with international law yield very little in terms of carbon leakage and efficiency.

Elliott et al. (2012) analyze the extent of emission reduction of a wide range of carbon tax schemes in Kyoto protocol Annex-B countries, the expected carbon leakage, and the effect of CBTA. They simulate both CBTA on embodied emissions as well as CBTA on emissions related to production technologies in importing countries. Using 2004 GTAP data through a computational general equilibrium model, they show the importance of global taxes: carbon taxes only in Kyoto protocol Annex-B have low potential to reduce emissions. They also find that CBTA on abating region's emissions can be significantly inferior at reducing emissions than CBTA on non-abating regions' emissions. This is mainly due to the lack of incentives for foreign producers to adapt less-polluting technologies.

[3] High income countries except for the abating regions, Brazil, China, India, Russia, rest of East Asia, rest of South Asia, rest of Europe and Central Asia, Middle East and North Africa, Sub-Saharan Africa, rest of Latin America Countries.

Our work follows the proposal of these three papers, with some differences. First, they focus on the broad effects of CBTA in terms of output, competitiveness or environmental goals using computational general equilibrium models. Instead, we propose a static analysis to show what tax level each policy design would imply at a product-based and at a country-based level. In this way the analysis provides different information. It shows not only the intensity of different CBTA metrics through the average effect for each country, but also the spread or concentration of CBTA designs among different products of different countries providing additional information to assess the feasibility of this policy.

Second, we focus in particular on the EU due to its position about carbon pricing. Indeed, on the one hand, the EU debate on pricing carbon emissions has a long history started in the early 1990s. Moreover, the EU is already implementing different policies for emission control such as the ETS or the European Energy Tax Directive (ETD), a tax on the use of energy products aimed at reducing emissions. Anyway, these main policies implemented so far are still weak or poorly performing.[4] For this reason there are ongoing political debates to strengthen them in order to reach the challenging environmental targets the EU has set itself.[5] Despite the political difficulties in advancing in carbon taxation in the EU, we believe it is important to revive the debate on implementing a harmonised EU carbon tax as a powerful climate change tool to reduce emissions. Since CBTA has already been feared as possible for complementing a carbon tax, it seems important to analyse all the critical issues that they would imply, among them what method should be used to compute them.

Third, since we take into account emissions embodied in trade flows, while the previous studies use the GTAP database we employ the World Input Output Database (WIOD) that is better suited with the scope of our analysis.

Finally, we also explore additional methodological issues that arise from the use of multi-region multi-sector models to compute the different CBTA regimes. In this paper we suggest the need of considering avoided emissions in order to compute CBTA based on emissions related to the abating region’s technology. Indeed, if tariffs are computed considering only (direct and indirect) emissions produced domestically, the fiscal load applied to foreign products would be lower than the fiscal treatment for domestic products: due to the adoption of CBTA, domestic goods would be indeed taxed based on their avoided emissions, being also the imported inputs taxed. So, to compute avoided emissions for analyzing border tax based on the domestic technology, we apply the so-called “domestic technology assumption” (DTA).

Concerning the use of DTA, a second issue regards international price differences. As we have analyzed in Arto et al. (2014), the usual way of estimating

[4]The European ETD currently in force fixes very low tax rates for the most part of fuel uses and does not explicitly tax energy products according to their carbon emissions; looking at the ETS, during the last years the carbon price has been too low to give a strong price signal (European Parliament and Council, 2009).

[5] In addition to the ETS Directive , in 2001 the European Commission already proposed to modify the ETD in order to introduce an explicit carbon tax component (European Commission, 2011).

emissions according the DTA could significantly bias the outcomes. The implicit assumption usually applied is that prices of imported goods are equal to prices of the same products produced at home. For this reason in this paper we estimate avoided emissions correcting for the differences in prices of imported and domestically produced goods using trade data in physical units.

2. Method

A CBTA is a tax on the emissions of products imported by any region or country to compensate for different carbon policies (and especially carbon taxes) on products from different origins that compete in the same market. The tax base of this tariff can be calculated in two ways. The first method, the so-called embodied emissions, takes into account that production processes are often global and emissions produced in each stage of production are produced in different places; it accounts for all emissions embodied in imports. The second method, the so-called avoided emissions, takes into account emissions contained in an identical hypothetical product produced entirely in the abating region or country; in this way it accounts for emissions avoided by importing goods.

Let us consider an example: the EU imports cans of tuna from Taiwan. This tuna has been fished in Korea, using boats and fishing rods produced in Japan. Emissions embodied in a can of tuna include emissions in Korea but also in Japan. Alternatively, emissions avoided in the EU by importing cans of tuna from Taiwan are the emissions that the EU would emit fishing the tuna and producing the can, the boat and the rods inside the EU.

We use an environmentally extended (ee) multi-regional input-output (MRIO) model to calculate emissions embodied in imports. In this case, let us consider a world consisting of *c* countries, each composed by *n* sectors.[6] Matrix **X** represents the inter-country inter-sector deliveries in the world, where its element x_{ij}^{rs} shows the amount of output from sector *i* in country *r* consumed as intermediate input by sector *j* in country *s*. Matrix **A** represents the world input structure, where each element a_{ij}^{rs} is obtained as $a_{ij}^{rs} = x_{ij}^{rs}/x_i^r$, being x_i^r the total output of sector *i* in country *r*. **A** permits to define the Leontief inverse $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$, where any element l_{ij}^{rs} reveals additional direct and indirect output that sector *i* of county *r* produces for an additional monetary unit of sector *j* in country *s*. An ee-MRIO adds information on emission intensity e_i^r obtained dividing total emissions by sector over total output produced by each sector. Using this additional information we compute $\mathbf{G} = \hat{\mathbf{e}}\mathbf{L}$, where any element g_{ij}^{rs} reveals the emissions that sector *i* of country *r* produces for an additional unit of sector *j* in country *s*.

Then, we re-allocate emissions by sector to emissions by product, taking into account that each sector can produce different products and also that any product can

[6] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A diagonal matrix with the elements of any vector on its main diagonal and all other entries equal to zero is indicated by a circumflex.

actually be produced by different sectors. Coming back to the previous example: let us consider that the Taiwanese cans for tuna are made of aluminum. These cans are mainly produced by the aluminum-processing sector. Imagine that in Taiwan some firms from the manufactured-food sector buy cans, whereas other firms buy aluminum and makes cans by themselves as a secondary production. To apply the CBTA to imported cans of tuna, the EU needs to know the emissions embodied in each can of tuna that cross the border from Taiwan to the EU regardless if the can has been produced by the aluminum-processing sector or by the manufactured-food sector. So, we use a rectangular matrix $\mathbf{U}$ of dimension [(*n* x *c*) x (*m* x *c*)] to link the information at a sector level to different products *m*. $\mathbf{U}$ is a diagonal block matrix, where u_{ik}^{rs} shows the share of product *k* of country *s* produced by sector *i* in country *r*. Finally emissions embodied in any product is obtained as a (m x c)-dimensional vector $\tilde{\mathbf{e}}$ equal to $\tilde{\mathbf{e}} = \mathbf{i}'\mathbf{GU}$, being $\mathbf{i}$ a one's vector of appropriate dimensions.

A similar procedure is necessary for emissions avoided by importing goods. In that case we use an environmentally-extended single region input-output (ee-IO) model applying the so-called domestic technology assumption (DTA). We calculate the amount of emissions that would have been contained in a domestic product if all its inputs were produced with the technology available domestically in region R. So, emissions by sector per unit of output are represented by $\mathbf{G_R} = \widehat{\mathbf{e_R}}\mathbf{L_R}$, where $\mathbf{e_R}$ is the vector of emission intensities for region R and $\mathbf{L_R}$ is the Leontief inverse derived from the matrix of total input coefficients of the region $\mathbf{A_T}$, which includes domestic and imported inputs. As before, emissions by product are calculated as $\tilde{\mathbf{e}}_\mathbf{R} = \mathbf{i}'\mathbf{G_R}\mathbf{U_R}$, where $\mathbf{U_R}$ is a (n x m) matrix showing the share of any product *k* produced by any sector *i* of the region.

Finally, we obtain the CBTA $\boldsymbol{\tau}$ by multiplying the tax rate *t* that the region is applying to the carbon content of domestic products times the emissions per monetary unit of imported product. For emissions embodied in imports we simply have $\boldsymbol{\tau} = t\tilde{\mathbf{e}}$, whereas the equivalent for emissions avoided by importing goods needs a further consideration. Given that the same product has different prices in different countries, we need to deflate foreign prices (see Arto et al., 2014). In this way we obtain the CBTA on avoided emissions $\boldsymbol{\tau}_\mathbf{R}$ as: $\boldsymbol{\tau}_\mathbf{R} = \left(\frac{p_k^s}{p_k^r}\right) t\tilde{\mathbf{e}}_\mathbf{R}$.

Following with our example, let us assume that EU fixes a domestic carbon tax rate *t* equal to 20 euro per tonne of CO_2. Let us also assume that the emissions to produce tuna cans in the EU are equal to 5 tonnes of CO_2 per thousand of euro produced. So, the carbon tax applied to EU tuna cans would be equal to 0.1 per monetary unit (a 10% tax). If the EU tuna can price p_{tuna}^{EU} is 10 euro, the tax applied to each tuna can is 1 euro. A CBTA on avoided emissions applies to foreign products the same fiscal treatment as to domestic products. Following with the example, it means to impose a tariff equal to 1 euro on each tuna can imported from abroad. Anyway, if the Taiwanese tuna can price p_{tuna}^{TAI} is 5 euro, the tariff per monetary unit is 0.2 instead of 0.1. In general terms, we apply a deflator per each product and each foreign country to express tariffs per monetary units.

3. Data description

The analysis requires information from two databases: WIOD database, available since April 2012 and updated in November 2013 (WIOD, 2013), and COMEXT database made available by Eurostat (Eurostat, 2015).

From WIOD database we use multi-regional symmetrical input-output table, international supply and use tables, and CO_2 emissions data. We use the multi-regional symmetrical input-output table at current prices for the year 2009.[7] This industry by industry table offers information in monetary terms (millions of dollars) on 41 countries (27 European counties, 13 other major countries in the world and all the remaining regions aggregated in a single "rest of the world" region), and 35 sectors. This table is needed to compute emissions embodied in foreign products in the ee-MRIO model. Second, we use the international supply and use tables for the same year to compute avoided emissions applying the ee-IO model. In this case we aggregate the 27 European countries in one single region, the EU, using the information from the other 14 countries to know the intermediate imports disaggregated by sector. We also use the international supply and use tables to get information desegregated by product and compute the matrices $\mathbf{U}$ and $\mathbf{U_R}$. The information is available for 59 CPA products. For CO_2 emissions data, we employ the environmental accounts always from WIOD. This satellite accounts have the same sector breakdown (35 sectors) and geographical coverage (41 countries) as the world IO tables. In particular, from the air emission accounts, we use data on CO_2 emissions (in 1000 tonnes) desegregated by sector.

From COMEXT database we use data on international trade, recorded following the 2002 CPA classification. COMEXT database contains statistics on trade among EU countries and between EU member states and global partners. Data are available for 283 trading partners and 881 products categories, and they are expressed in monetary terms (euro) as well as in physical term (kilograms). In particular, we use the information on the 14 non-EU countries available in WIOD, and information on 217 products[8] in order to calculate the deflators and to obtain CBTA on avoided emissions**.**[9]

4. Results

In this paper we consider the EU as a single region. Assuming that the EU has a domestic carbon tax, we simulate a hypothetical CBTA that the EU would apply on products imported from non-EU countries in order to "level the field". We use 2009 as the reference year.

[7] See the thesis Appendix I for a detailed description of WIOD database.
[8] See Appendix A for a complete list of the 217 products used from COMEXT.
[9] Appendix B explains in detail how deflators are computed. It also shows the importance of using the highest data desegregation available, in order to avoid biases in the deflators obtained.

In the simulation, first, we assume that the EU has a domestic carbon tax equal to 20 euro per ton of CO_2 emitted applied to all sectors. This tax level is realistic since, in fact, it was the tax rate proposed, but not approved, by the European Commission to reform the European Energy Tax Directive (European Commission 2011, Rocchi et al. 2014). Although we set the carbon taxation at a specific value to interpret results more easily, the analysis could be expressed in a general form for any tax level *t*.[10] Second, we assume that non-EU countries are not implementing any emission reduction policy.[11] Finally, we assume that the EU applies a CBTA on products imported from non-EU countries to compensate for the domestic carbon tax, without considering further emission reduction policies the EU could be implementing.

The CBTA rates are calculated by product. Although WIOD data are disaggregated in 59 different categories, we focus our analysis only on 22 manufactured products.[12] We exclude services because CBTA is a system of customs duties applied to products physically imported. Regarding agricultural products and raw material, the EU does not likely have all the resources to produce domestically all agricultural products and raw material. Instead, it imports some goods that it does not produce. The disaggregation available in data does not permit to distinguish between products that the EU is importing but also producing domestically from that products that the EU does not have and, therefore, it needs to import from abroad. Since CBTA tariffs would be imposed on products that have an equivalent good produced domestically to level out different fiscal treatments applied to domestic and foreign goods, we exclude agricultural products and raw material from the analysis.

The structure of this section is as follows. In section 4.1 we compare at a global level the CBTA system computed following the two methods proposed: rates based on embodied emission and rates based on avoided emissions. Then, we present the analysis at a product level and at a country level in Sections 4.2 and 4.3 respectively.

[10] Since tax rates are a linear transformation of the emission content of each product, rates in a general form can be obtained multiplying the results obtained times *t*/20. Anyway, other duties would not change the comparison between countries and sectors found.

[11] If foreign countries already apply carbon policies, some compensation should be applied. Moreover, literature suggeststhat in a CBTA system the abating regions could also exempt their export from the domestic carbon taxation, in order to avoid the competitive disadvantage of domestic firm in the world market (Holzer, 2010). Anyway, this policy option is out of the scope of our analysis.

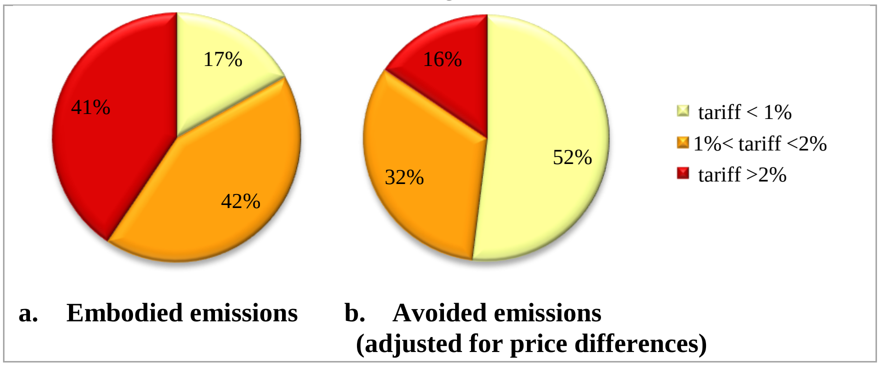
[12] Rates shown in this analysis are average tariffs, assuming a unique homogeneous good for each WIOD classification. Each WIOD category aggregates a wide variety of products. Reason why, starting from the results found in this analysis, a possible extension of this work could be a more desegregated analysis focused on the products that would be charged most under a CBTA scheme. Anyway, this is not possible with WIOD data that instead permits a multi-regional analysis.

4.1. CBTA on embodied emissions and CBTA on avoided emissions

Table 1 shows CBTA rates by product, comparing rates computed on embodied emissions (white columns) and rates computed on avoided emissions (grey columns) for each non-EU country. Rates are computed per monetary unit imported. So, tax rates on embodied emissions vary by country because each country has a different technology and a different price for each product. Although emissions avoided by the EU when it imports a product are the same independently of what country the product is imported from, also tax rates computed considering avoided emissions vary among countries due to international differences in prices.

To give a first overall picture, we compare the two different tax designs considering all the products and all the countries. Results in aggregate terms are displayed in Figure 1 in which we distinguish products that would be more strongly affected through tariffs higher than 2%, products that would be mildly affected (with tariffs between 1% and 2%), and products less affected (with tariffs lower than 1%). As expected, CBTA tariffs would be higher in a system based on embodied emissions (Figure 1.a) in which rates would be more than 2% for 41% of the totality of the 308 products considered (22 products for each of the 14 countries), more than twice as much as the products heavily taxed in a system calculated on avoided emissions. A similar number of products would be mildly affected (42% and 32% respectively) under the two systems, while much more products would pay low tariffs under a system based on avoided emissions.[13]

Figure 1. Percentage of products based on their tariff size, under the two different CBTA designs



Source: own elaboration.

[13] Appendix D provides a similar comparison of the results obtained for a system based on avoided emissions, considering data in monetary terms without price adjustment, or deflating data to take into account international differences in prices; the comparison shows the bias in the results that would result when international price differences are not considered.

Table 1. Tariffs on embodied emissions and tariffs on avoided emissions, in percentage, by product and by country, 2009

		AUS		BRA		CAN		CHN		IDN		IND		JPN	
		Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions
15	Food products and beverages	1.1	1.0	0.7	1.6	1.0	0.5	2.0	0.6	0.9	1.8	3.7	0.8	0.6	0.3
16	Tobacco products	1.1	0.8	0.7	2.3	1.0	0.4	2.0	0.5	0.9	3.8	3.7	3.0	0.6	1.4
17	Textiles	1.2	0.7	0.6	1.2	1.2	1.5	2.8	2.1	3.8	2.5	3.8	1.6	0.8	0.5
18	Wearing apparel	1.1	0.7	0.6	1.0	1.0	0.4	2.8	1.5	3.8	1.0	3.8	1.4	0.8	0.2
19	Leather and leather products	1.1	1.8	0.5	0.9	0.9	0.9	2.1	2.6	1.8	1.0	2.3	1.1	0.7	0.3
20	Wood and products of wood and cork	1.2	0.8	0.5	0.8	1.1	0.9	2.9	0.9	1.6	0.6	5.1	0.7	0.9	0.2
21	Pulp, paper and paper products	1.1	0.7	0.7	0.8	1.1	0.7	3.9	0.5	2.8	0.6	5.3	0.6	0.9	0.1
22	Printed matter and recorded media	1.0	0.6	0.7	0.5	1.0	0.4	3.9	1.9	2.8	2.6	5.3	2.3	0.9	0.3
23	Coke, refined petroleum products	2.1	10.2	1.4	2.8	3.4	3.2	5.1	1.2	1.6	1.7	4.9	1.8	1.7	1.8
24	Chemicals, chemical products	2.0	1.0	1.1	3.5	2.2	1.3	5.5	2.5	2.2	8.1	5.1	2.4	1.6	0.4
25	Rubber and plastic products	1.5	0.5	0.8	0.7	1.2	0.8	4.2	1.4	2.1	1.1	4.5	1.3	1.1	0.4
26	Other non-metallic mineral products	4.1	1.4	3.2	3.6	2.9	4.4	10.1	7.6	12.3	6.1	12.9	4.7	3.7	0.7
27	Basic metals	2.2	0.5	1.6	1.1	2.0	0.3	6.4	1.7	6.7	0.5	8.3	1.7	1.9	0.6
28	Fabricated metal products	2.6	1.0	1.6	1.9	1.9	1.1	6.2	3.2	6.7	2.3	7.8	3.0	1.9	0.9
29	Machinery and equipment n.e.c.	1.7	0.5	0.8	1.1	1.1	0.4	4.0	1.7	1.5	1.3	4.5	1.4	0.9	0.5
30	Office machinery and computers	0.9	0.2	0.8	0.4	1.0	0.3	3.3	0.7	0.0	1.4	3.8	1.1	0.9	0.3
31	Electrical machinery	1.3	0.2	0.8	1.3	1.0	0.2	3.3	1.2	1.8	1.0	4.2	1.3	0.9	0.3
32	Radio, television and comm. eq.	1.4	0.7	0.8	1.3	1.0	0.4	3.3	1.4	1.8	0.7	3.8	2.2	0.9	0.7
33	Medical and optical instruments	1.3	0.3	0.8	1.2	1.0	0.5	3.3	4.2	1.8	0.8	4.0	1.9	0.9	0.5
34	Motor vehicles, trailers	1.2	0.4	0.7	0.7	1.0	0.6	3.3	1.6	1.3	0.8	4.1	0.9	0.9	0.5
35	Other transport equipment	1.2	1.0	0.7	0.6	1.0	0.9	3.3	1.1	1.3	2.2	4.5	1.5	0.9	0.6
36	Furniture; other manufactured goods	1.3	0.2	0.6	8.7	1.0	0.4	3.3	1.6	2.1	1.6	2.9	0.9	1.0	0.4

Source: own elaboration.

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; USA: United States; ROW: Rest of the World.

Table 1. (Continuation) Tariffs on embodied emissions and tariffs on avoided emissions, in percentage, by product and by country, 2009

		KOR		MEX		RUS		TUR		TWN		USA		ROW	
		Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions
15	**Food products and beverages**	1.6	0.5	1.1	0.8	2.2	1.7	1.2	0.7	1.5	1.2	1.4	0.9	1.3	1.0
16	**Tobacco products**	1.6	1.0	1.1	0.5	2.2	1.0	1.2	0.7	1.5	0.8	1.4	0.9	1.3	2.2
17	**Textiles**	2.1	1.3	1.6	1.2	2.6	2.0	1.1	1.4	2.7	1.5	1.5	0.8	1.7	2.0
18	**Wearing apparel**	2.1	1.4	1.6	0.6	2.6	0.8	1.1	0.9	2.7	1.7	1.4	0.7	1.6	1.3
19	**Leather and leather products**	1.6	0.7	1.1	0.8	2.7	1.4	0.9	1.2	1.6	1.4	1.4	1.1	1.5	1.1
20	**Wood and products of wood and cork**	1.9	0.3	1.4	0.3	3.3	1.3	2.2	0.6	1.5	0.4	1.8	0.6	1.5	0.9
21	**Pulp, paper and paper products**	2.1	0.5	1.4	0.7	3.1	0.7	1.3	0.8	2.6	0.3	1.3	0.5	1.5	0.7
22	**Printed matter and recorded media**	2.1	1.5	1.4	0.3	3.1	0.7	1.3	1.5	2.6	0.8	1.1	0.5	1.5	1.2
23	**Coke, refined petroleum products**	2.6	1.8	3.2	16.8	5.4	2.0	2.5	1.6	3.4	1.9	2.3	2.9	3.5	2.0
24	**Chemicals, chemical products**	2.7	2.2	1.7	2.3	9.5	3.3	1.4	2.6	3.8	1.6	1.9	0.8	3.4	1.5
25	**Rubber and plastic products**	2.1	0.8	1.6	0.6	4.5	0.7	1.9	1.0	2.3	0.9	1.4	0.4	8.0	1.0
26	**Other non-metallic mineral products**	7.4	1.6	5.2	3.3	12.8	7.8	7.4	4.9	12.3	4.2	4.9	1.3	7.1	6.4
27	**Basic metals**	4.1	0.9	2.3	1.2	10.3	1.3	2.7	2.0	4.2	1.3	1.9	0.9	2.8	0.7
28	**Fabricated metal products**	4.1	2.2	2.2	1.4	10.3	3.0	2.5	2.6	4.2	2.9	1.9	0.7	2.8	1.5
29	**Machinery and equipment n.e.c.**	1.9	1.1	1.3	0.7	4.5	1.2	1.5	1.4	1.8	1.1	1.0	0.5	1.9	0.6
30	**Office machinery and computers**	1.7	0.3	1.6	0.3	4.3	0.3	0.9	0.6	1.7	0.4	0.7	0.4	1.9	0.4
31	**Electrical machinery**	1.7	0.6	1.6	0.4	4.3	1.1	2.3	1.2	1.7	0.5	0.7	0.2	2.0	0.6
32	**Radio, television and comm. eq.**	1.7	0.5	1.6	0.4	4.3	0.8	1.2	1.0	1.7	0.7	0.7	0.6	1.9	1.1
33	**Medical and optical instruments**	1.7	1.3	1.6	0.8	4.3	0.2	1.2	3.1	1.7	1.6	0.7	0.4	2.2	0.5
34	**Motor vehicles, trailers**	1.8	0.9	1.1	0.6	3.4	1.0	1.2	0.7	1.7	0.9	1.1	0.5	1.5	0.8
35	**Other transport equipment**	1.8	0.2	1.1	1.6	3.4	3.1	1.3	0.8	1.7	0.9	1.1	0.8	1.5	0.4
36	**Furniture; other manufactured goods**	1.9	1.0	1.7	1.2	4.1	0.7	1.5	1.2	1.9	1.2	0.9	0.7	4.2	1.1

Source: own elaboration.

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; USA: United States; ROW: Rest of the World.

4.2. Analysis at the product level

In this Section we analyze the results from the two CBTA systems: on embodied emissions and on avoided emissions. For each system we measure the impact first considering only the tax rates applied to different products and then taking into account also trade volume of each product.

CBTA on embodied emissions

If we look at the tariffs obtained under a system based on embodied emissions, the products mostly affected would be "Other non-metallic mineral products" (26).[14] For these products, the average rate would be higher than 2% in all the 14 non-EU countries, being particularly high (more than 10%) for products imported by China (10.1%), Indonesia (12.3%), India (12.9%), Russia (12.8%), and Taiwan (12.3%). These products are the ones whose emissions depend most on exporting countries' technologies: for all the countries considered except for Canada the emissions produced by each country are at least the 90% of embodied emissions. Anyway, in different countries emissions come from different production phases. In Indonesia and India these emissions are largely produced by the sector producing "other non-metallic mineral products". In China and Russia an important share of emissions (32.1% and 32.8%) are embodied in the electricity need to produce them. In Taiwan, one fifth of embodied emissions come instead from the extraction of raw material.

Other products that would be particularly affected are "Basic metals" (27), and "Fabricated metal products" (28). For these products, rates would be high in particular for Russia (10.3% in both cases), India (8.2% and 7.4%), Indonesia (6.7% in both cases), and China (6.3% and 6.2%). China, India, Russia and Taiwan would also have the highest rates on other energy-intensive products as "Coke, refined petroleum products" (23) and "Chemicals, chemical products" (24). For all these products, the analysis reveals a pattern of embodied emissions very similar to the one described for "Other non-metallic mineral products": on average roughly the 80% of embodied emissions are generated in the exporting country. For "Basic metals" (27), and "Fabricated metal products" (28) produced in Russia and Indonesia emissions are mainly due to the intensive use of energy of the producing sectors; for Chinese and Indian products belonging to these classifications, and for "Coke, refined petroleum products" (23) or "Chemical products" (24) from the countries listed before, roughly half of the emissions embodied are due to the electricity needed to produce them. Some of these products would also have rates higher than 2% when imported from Australia, Canada, Korea, Mexico, Turkey and USA, but in this case the contribution to emissions of the electricity sector would be much lower.

There are finally other products that would be taxed most, but just when produced and imported by few countries, in particular China, India, and Russia. For these three countries, many products would be taxed with rates higher than 3%: "Wood and products of wood and cork" (20), "Pulp, paper and paper products" (21), "Printed matter and recorded media" (22), "Machinery and equipment" (29), "Office machinery and computers" (30), "Electrical machinery" (31), "Radio, television, and communication equipment" (32), "Medical and optical instruments" (33), "Motor vehicles, trailers" (34), "Other transport equipment" (35). Once again, what these three countries have in common is that for all these products more than 90% of embodied emissions are generated in the exporting country; they also have in common a relevant role of the electricity sector in creating the emissions embodied in these products: for these products, on average, 47% of embodied emissions are due to the electricity sector.

[14] The number in parenthesis after a product's name refers to the product's number in Table 1.

So, to conclude, looking at tax rates at a product level, the main products affected would be the energy-intensive products, in particular when imported from China, Indonesia, India, Russia, Korea, and Taiwan; the many emissions embodied in energy-intensive products coming from these countries are clearly related to the technology needed to produce them, but also, especially for China, India, and Russia, to the highly polluting electricity sector.

Comparing the results obtained simulating CBTA on avoided emissions with the previous results, two main characteristics are worth being noticed.

First, the emissions the EU is avoiding, or in other terms the emissions that the EU would have produced if all products were made domestically, are on average very few. This implies that in general a system based on avoided emissions implies tariffs lower than in a system based on embodied emissions: only for 15% of the products analyzed (42 out of 308) a system based on avoided emissions would imply rates higher than a system based on embodied emissions.

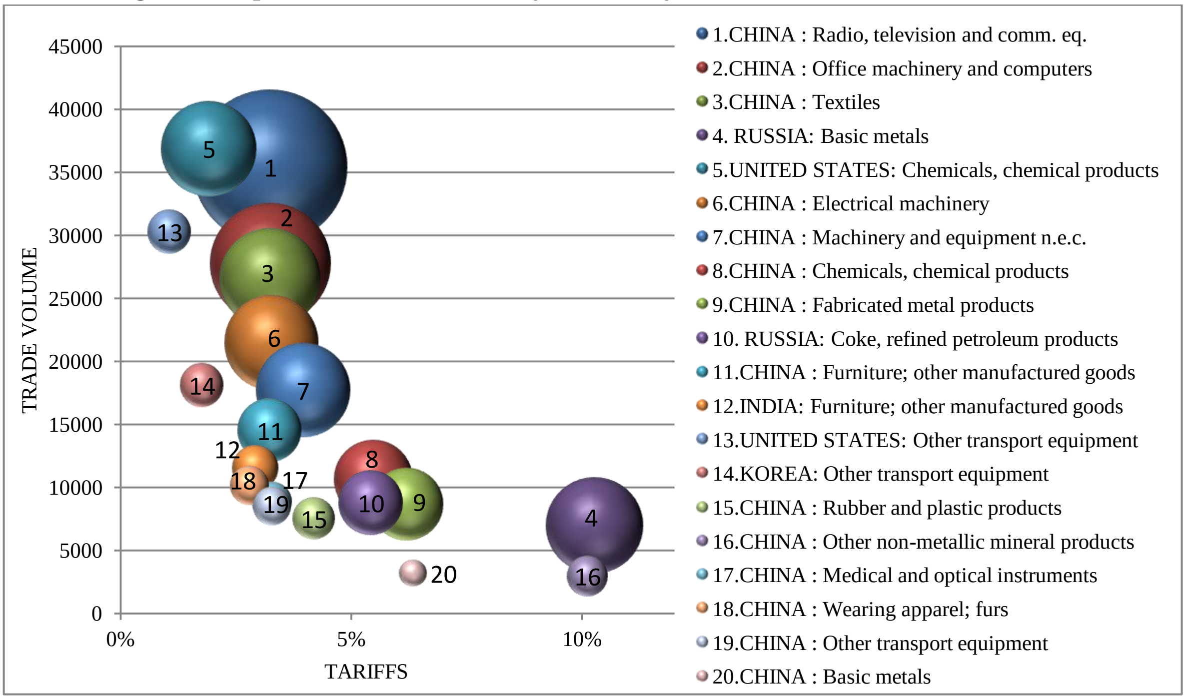
Second, analyzing the 15% of goods that would be more affected by a system based on avoided emissions, products that would be taxed more are “Tobacco products” (16) imported from Brazil, Indonesia and Japan; “Textiles” (17) from Brazil, Indonesia and Turkey; “Leather products” (19) from Austria, Canada, and Turkey; and “Chemical products” (24) imported from Brazil, Indonesia, and Turkey. This means that if these specific products were entirely produced in the EU, they would produce a bigger amount of emissions. These results also shows that CBTA based on avoided emissions would be higher than CBTA on embodied emissions mainly in three countries: Brazil, Indonesia, and Turkey.

Tax rates applied to different products provide a measure of the impact that CBTA would have. Anyway, its effect would depend also on the total value of goods imported in the EU: a very high tax on basic metals imported from India might be insignificant if India trades just very few units with the EU. Taking into account also trade volume reveals different information.[15] Figure 2 shows the 20 products, over the 308 analyzed, mostly affected by a CBTA system based on embodied emissions: these products would indeed bear more than the 60% of the total effect of the policy, represented by the width of each bubble, computed as the tax rates (shown in the horizontal axis) multiplied by the total value imported in the EU (shown in the vertical axis).[16] The main result that Figure 2 shows is that 14 out of 20 products would be imported from China that alone would sustain roughly 30% of the policy’s effect. The ranking of these products seems to be more related with the volume of trade than the severity of the rates imposed: the three most affected products, for example, would not be energy-intensive products, but “Radio, television, and communication equipments” (32), “Office machinery and computers” (30), and “Textiles” (17).

[15] Although the volume of goods imported would clearly change following the CBTA implementation, we propose a static quantification of the policy effect to take into account the actual size of trade flows.

[16] The region that would actually bear the most part of a CBTA system is the region “Rest of the World” (RoW) that would pay roughly the 40% of the policy’s cost. Anyway, we do not analyse this region in detail because it aggregates several and different countries, and it would not be possible to provide a more detailed explanation to the results found.

Figure 2. 20 products most affected by a CBTA system based on embodied emissions.



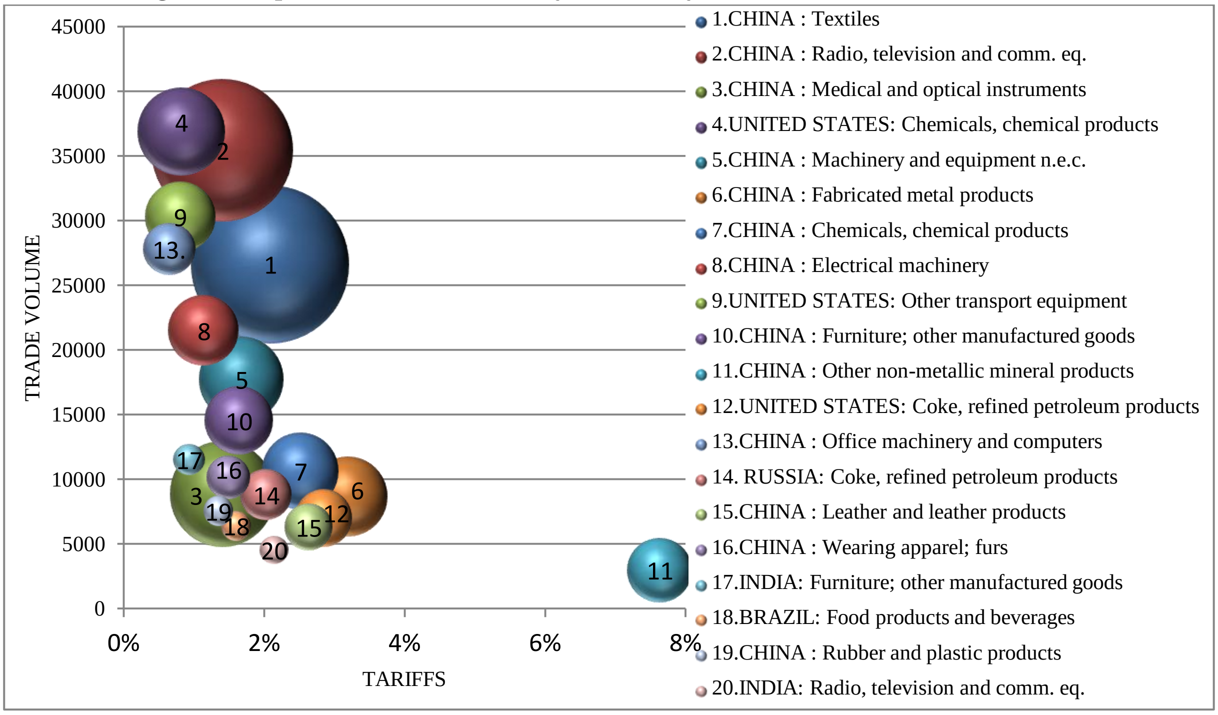
Source: own elaboration.

Another interesting result is that two of the mostly affected products come from USA: “Chemical products” (24) would be the 5th most affected product, “Other transport equipment” (35) the 13th. Also in this case it is due more to the volume of trade than to high tariffs (respectively 1.9% and 1.1%). Conversely, very high tax rates more than the trade volume explain the cost the reform would imply on Russian products classified “Coke, refined petroleum products” (23), and “Basic metals” (27).

Also for the CBTA based on avoided emissions we show, besides tariffs obtained, the effect of CBTA considering both the tax rates obtained and the volume of trade (Figure 3). Although the impact in absolute terms would be different, the ranking of the most affected products would change only partially. The reason is that, as previously described, the policy impact relies more on the volume of trade than on the severity of the tariffs imposed. Anyway, for some products, the two systems would imply a strongly different impact. This would be the case of “Basic metals” (27) produced in Russia, which under a system based on embodied emissions would be the 4th category mostly affected bearing the 4.4% of the total policy impact, and under a system based on avoided emissions it would bear the 1.1% of the total impact instead. Another example would be Chinese “Medical and optical instruments” (33) that would sustain only the 1.6% of total effect in the first scenario analyzed and the 4.6% in the second one.

In the next Section we focus more in deep on specific countries to show the overall effect of the two tax designs for any of them.

Figure 3. 20 products most affected by a CBTA system based on avoided emissions.



Source: own elaboration.

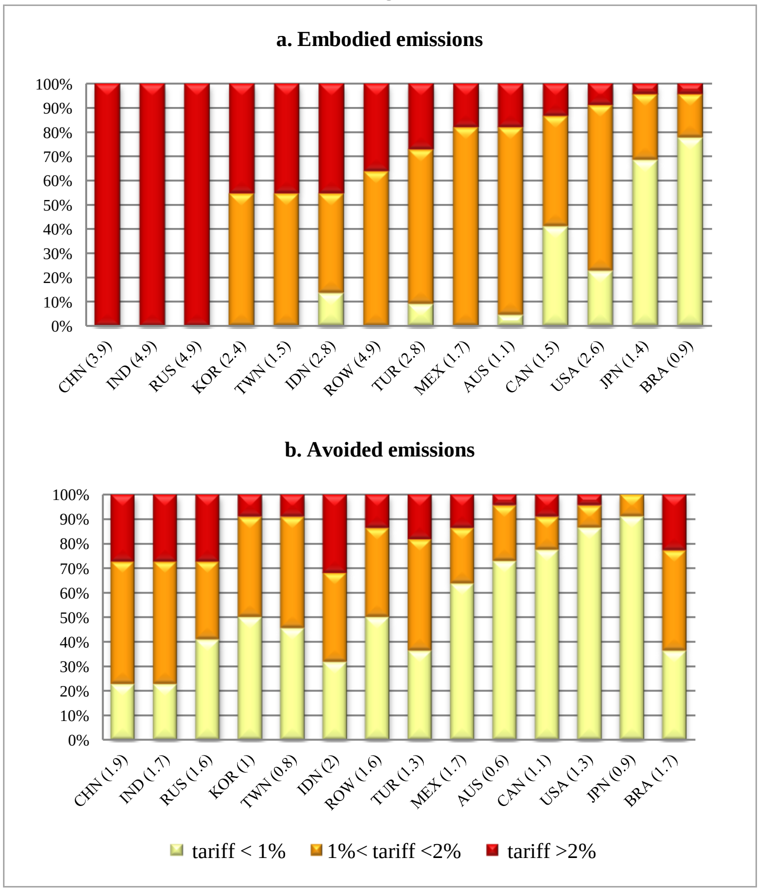
4.3. Analysis at the country level

Looking at the tax rates, differences between the two systems can also be found at a country level with important differences across them (see Figure 4). In Figure 4.a countries are ordered based on the spreading of the CBTA on embodied emissions; and in Figure 4.b the equivalent for the CBTA on avoided emissions. For each country the label also shows, in parenthesis, the average tariff applied.[17] For three countries, China, India, and Russia, the differences between the two approaches would be very strong. Considering embodied emissions, 100% of their products would be charged with tariffs higher than 2%, and the average tariff would be, respectively, 3.9%, 4.9%, and 4.9%. Considering avoided emissions only 27% of products would be mostly affected, and the average tariffs would be 1.9%, 1.7%, and 1.6%.

Although in a less decisive way, also for almost all the other countries a CBTA system based on embodied emissions would have a stronger impact than a CBTA based on avoided emissions for both the level of the rates and their spread across products. The difference is less strong for Turkey, USA, Canada, Indonesia, Japan, and Australia. Brazil is the country that performs differently from the rest of the regions: in this case a tariff system based on avoided emissions would be worse than a system based on embodied emissions. In particular, 16 products (73%) would be taxed more under a system designed on avoided emissions.

[17] The averages in Figure 4 are computed as simple averages without taking into account trade volumes.

Figure 4. Percentage of products based on their tariff size, by country, under the two different CBTA designs



Source: own elaboration.

Finally, also at a county level, it is interesting to show the effect of the two different CBTA systems in terms of the cost that they would imply. To do so, in Table 2 we express the impact of the policy for each non-EU country in three different ways.

First, we show weighted rates that represent the impact as a percentage of the total value of manufactures that any non-EU country exports to the EU (first two columns of Table 2). So, for example, for Australia the total impact of a system based on embodied emissions would represent the 1.6% of the value of manufactures that the country exports to the EU. As found before, under a system based on embodied emissions the three most affected countries are Russia, India, and China. For these countries the policy would imply an impact equal to, respectively, 7.2%, 4.0%, and 3.6% of the value of manufactures exported to the EU. The ranking changes under a system based on avoided emissions. In this case Indonesia would be the most affected country, paying the 1.9% of the value of manufactures exported to the EU.

The result is different when we measure the impact as a percentage of the total trade value that each non-EU country exports to the EU (columns 3 and 4 of Table 2). The main change regards Russia. Being raw material the most important trade flow with the EU, the cost of CBTA based on embodied (avoided) emissions would be only the 1.8% (0.4%) of the total value imported from Russia.

The last two columns of Figure 2 show what share of the policy impact each country would bear. An interesting result regards USA: although a CBTA on embodied (avoided) emissions would represent only the 1.3% (0.8%) of the manufactures' value imported from USA, and the 0.6% (0.4%)

of the total value imported, USA would be the third country in terms of share of the policy cost, bearing the 7.5% (8.8%) of the total cost of the policy. This is due to the fact that the volume of trade between USA and the EU is very large.

Table 2. CBTA cost for each non-EU country

Non-EU Country	Percentage of the value of manufactures exported by any non-EU to the EU				Percentage of total trade value exported by any non-EU to the EU				Country's share of the policy cost			
	Embodied emissions		Avoided emission		Embodied emissions		Avoided emission		Embodied emissions		Avoided emission	
Australia	1.6	[9] *	1.1	[8]	0.5	[13]	0.3	[12]	0.3	[14]	0.5	[14]
Brazil	0.8	[14]	1.7	[4]	0.3	[14]	0.7	[7]	0.6	[12]	2.4	[9]
Canada	1.5	[11]	0.9	[10]	0.5	[12]	0.3	[13]	0.7	[11]	0.9	[12]
China	3.6	[3]	1.7	[3]	2.9	[1]	1.4	[1]	29.6	[2]	29.1	[2]
Indonesia	2.1	[6]	1.9	[1]	1	[8]	0.9	[3]	0.8	[10]	1.5	[11]
India	4	[2]	1.4	[5]	2.2	[2]	0.8	[5]	5.3	[5]	3.9	[5]
Japan	1.1	[13]	0.6	[14]	0.9	[9]	0.5	[9]	2.4	[8]	2.6	[7]
Korea	2	[7]	0.7	[13]	1.6	[4]	0.6	[8]	3.5	[6]	2.4	[8]
Mexico	1.5	[10]	0.8	[11]	0.5	[11]	0.3	[14]	0.4	[13]	0.5	[13]
Russia	7.2	[1]	1.8	[2]	1.4	[5]	0.4	[11]	5.7	[4]	2.9	[6]
Turkey	1.7	[8]	1.4	[6]	1.3	[7]	1	[2]	3	[7]	4.9	[4]
Taiwan	2.3	[5]	1.1	[9]	1.8	[3]	0.9	[4]	1.6	[9]	1.6	[10]
USA	1.3	[12]	0.8	[12]	0.6	[10]	0.4	[10]	7.5	[3]	8.8	[3]
RoW	2.6	[4]	1.3	[7]	1.4	[6]	0.7	[6]	38.5	[1]	38	[1]

Source: own elaboration.

*Countries ranking: [1] is the most affected country, [14] is the less affected.

5. Conclusions

This paper has analyzed CBTA. This policy is designed to avoid one of the drawbacks of emission control instrument applied only on domestic products. It consists in tariffs on imports that level out different treatments on domestic and foreign products that compete in the same market. In particular, we have analyzed the metric of CBTA, one of the topics of the debate. We have assumed a 20 euro CO_2 tax applied in the EU, and we have simulated two different possible CBTA systems. The first is based on emissions embodied in imports. The second is based on emissions the EU would produce to make the same product integrally within its borders, which is on avoided emissions.

Looking at the main results, the two mechanisms would imply a different outcome in aggregate terms. In fact, a system designed considering embodied emissions would cost 2.5% of the total value of manufactures imported in the EU from the non-EU countries (a 1.3% under a system based on avoided emissions). This result is in line with the findings of the existing literature. The difference between the two methods varies depending on the countries considered. For some countries

(Australia, Indonesia, Japan, and USA) the rates computed under the two systems would be similar, while for other countries (such as China, India, or Russia) the difference would be really high.

On the one hand a possible conclusion could be that a system based on avoided emissions is likely to be more acceptable due to its lower cost and due to the fact that products would not be differently treated depending on their origin.

On the other hand the analysis also makes it clear that a system based on avoided emissions would not be targeted at the real pollution content of the different goods. This conclusion is exemplified by the case of Brazil. Under a system based on avoided emissions Brazilian products would be taxed more than under a system that takes into account the emissions actually contained in them. This is due to the fact that, for this country, the average content of emissions is limited especially thanks to an ex electricity production system with low carbon content. A system based on avoided emissions should take into account cases such as Brazil. Otherwise it would create a disincentive for emission control, and it would go in the opposite direction of a policy, such as a carbon tax, which seeks to create incentives to reduce emissions.

The analysis also shows that, under both metrics, China would largely be the main target country of an EU CBTA system. This is caused by its highly polluting production system and electricity sector. It is also due to the volume of trade that exists between the EU and China. Moreover, given its crucial role in international trade relations, Chinese production system is also responsible for an important share of emissions embodied in products, especially electronic ones, produced by other countries. Based on this result, the prospect that the EU implements a CBTA system could serve as political leverage in reaching an international agreement after Kyoto.[18]

In terms of analysis by products, two groups of goods would be most affected. On the one hand there are energy intensive products such as coke, refined petroleum products, chemicals, chemical products, other non-metallic mineral products, basic metals, and fabricated metal products. Also this result is in line with the existing literature. On the other hand the analysis reveals that also electronic products, such as radios, televisions, and office machineries, would be highly exposed to CBTA due to the large volume traded with the EU. China, India, and Russia would be the most affected countries. When the volume of trade is considered, China assumes a predominant role. Also USA would bear an important share of the CBTA cost under both designs, although the policy’s cost would represent less than the 2% of the manufactures the country exports to the EU. The results at a product level might suggest another element in the debate on the metric of CBTA. The impact of the policy would fall largely on two groups of products for different reasons. Energy-intensive products are among the most affected goods due to their carbon content. Non-energy intensive products, such as electronics, would also be strongly affected due to the large volume traded in the EU. So an alternative solution to the higher impact of a CBTA based on embodied emissions could be to limit the tariff system only to certain products. This would also facilitate practical implementation of CBTA. In fact, it reduces the amount of information needed. A possible criterion to select products could consider the most exposed to the risk of leakage. This suggests the need of further analysis at a product level on what products could suffer of carbon leakage most.

[18] Tariffs on imported goods have also been proposed in environmental policy as a measure to penalize countries that do not enter agreements on global problems such as climate change. Since this use of carbon tariffs does not necessarily imply tax on carbon emissions, some authors suggest that it would be easier to apply a general sanction tariff equal for all the goods imported from countries that do not enter the climate club (Nordhaus, 2015).

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6. Appendices

Appendix A. COMEXT products considered

Num.	COMEXT code, Product	Num.	COMEXT code, Product
1	1511 fresh and preserved meat (except poultry)	45	1810 leather clothes
2	1512 fresh and preserved poultry meat	46	1821 work wear
3	1513 meat and poultry meat products	47	1822 outerwear
4	1520 processed and preserved fish and fish products	48	1823 underwear
5	1531 processed and preserved potatoes	49	1824 other wearing apparel and accessories n.e.c.
6	1532 fruit and vegetable juices	50	1830 furs; articles of fur
7	1533 processed and preserved fruit and vegetables n.e.c	51	1910 leather
8	1541 crude oil and fats	52	1920 luggage, handbags and the like; saddlery and harness
9	1542 refined oils and fats	53	1930 footwear
10	1543 margarine and similar edible fats	54	2010 wood, sawn, planed or impregnated
11	1551 dairy products	55	2020 veneer sheets; plywood, laminboard, particle board, fibre board and other panels and boards
12	1552 ice cream and other edible ice	56	2030 builders' joinery and carpentry, of wood
13	1561 grain mill products	57	2040 wooden containers
14	1562 starches and starch products	58	2051 other products of wood
15	1571 prepared animal feeds for farm animals	59	2052 articles of cork, straw and plaiting
16	1572 prepared pet food	60	2111 pulp
17	1581 bread, fresh pastry goods and cakes	61	2112 paper and paperboard
18	1582 rusks and biscuits; preserved pastry goods and cakes	62	2121 corrugated paper and paperboard and containers of paper and paperboard
19	1583 sugar	63	2122 household and toilet paper and paper products
20	1584 cocoa; chocolate and sugar confectionery	64	2123 paper stationery
21	1585 macaroni, noodles, couscous and similar farinaceous products	65	2124 wallpaper
22	1586 coffee and tea	66	2125 other articles of paper and paperboard n.e.c.
23	1587 condiments and seasonings	67	2211 books
24	1588 homogenised food preparations and dietetic food	68	2212 newspapers, journals and periodicals, appearing at least four times a week
25	1589 other food products	69	2213 newspapers, journals and periodicals, appearing less than four times a week
26	1591 distilled alcoholic beverages	70	2214 sound recordings
27	1592 ethyl alcohol	71	2215 postcards, greeting cards, pictures and other printed matter
28	1593 wines	72	2222 printing services n.e.c.
29	1594 cider and other fruit wines	73	2224 composition and plate-making services
30	1595 other non-distilled fermented beverages	74	2310 coke oven products
31	1596 beer made from malt	75	2320 refined petroleum products
32	1597 malt	76	2330 nuclear fuel
33	1598 mineral waters and soft drinks	77	2411 industrial gases
34	1600 tobacco products	78	2412 dyes and pigments
35	1710 textile yarn and thread	79	2413 other basic inorganic chemicals
36	1720 textile fabrics	80	2414 other basic organic chemicals
37	1740 made-up textile articles, except apparel	81	2415 fertilizers and nitrogen compounds
38	1751 carpets and rugs	82	2416 plastics in primary forms
39	1752 cordage, rope, twine and netting	83	2417 synthetic rubber in primary forms
40	1753 nonwovens and articles made from nonwovens, except apparel	84	2420 pesticides and other agro-chemical products
41	1754 other textiles n.e.c.	85	2430 paints, varnishes and similar coatings, printing ink and mastics
42	1760 knitted or crocheted fabrics	86	2441 basic pharmaceutical products
43	1771 knitted and crocheted hosiery	87	2442 pharmaceutical preparations
44	1772 knitted and crocheted pullovers, cardigans and similar articles	88	2451 glycerol, soap and detergents, cleaning and polishing preparations

Source: own elaboration from COMEXT database.

Appendix A. (Continuation) COMEXT products considered

Num.	COMEXT code, Product	Num.	COMEXT code, Product
89	2452 perfumes and toilet preparations	137	2741 precious metals
90	2461 explosives	138	2742 aluminium and aluminium products
91	2462 glues and gelatines	139	2743 lead, zinc and tin and products thereof
92	2463 essential oils	140	2744 copper products
93	2464 photographic chemical material	141	2745 other non-ferrous metal products
94	2465 prepared unrecorded media	142	2811 metal structures and parts of structures
95	2466 other chemical products n.e.c.	143	2812 builders' carpentry and joinery of metal
96	2470 man-made fibres	144	2821 tanks, reservoirs and containers of metal
97	2511 rubber tyres and tubes	145	2822 central heating radiators and boilers
98	2512 retreaded pneumatic tyres, of rubber	146	2830 steam generators (except central heating hot
99	2513 other rubber products	147	2861 cutlery
100	2521 plastic plates, sheets, tubes and profiles	148	2862 tools
101	2522 packaging products of plastics	149	2863 locks and hinges
102	2523 builder's ware of plastic	150	2871 steel drums and similar containers
103	2524 other plastic products	151	2872 light metal containers
104	2611 flat glass	152	2873 wire products
105	2612 shaped and processed flat glass	153	2874 fasteners, screw machine products, chain and springs
106	2613 hollow glass	154	2875 other fabricated metal products n.e.c.
107	2614 glass fibres	155	2911 engines and turbines except aircraft, vehicle and cycle engines
108	2615 other glass, processed, including technical glassware	156	2912 pumps and compressors
109	2621 ceramic household and ornamental articles	157	2913 taps and valves
110	2622 sanitary ceramic fixtures	158	2914 bearings, gears, gearing and driving elements
111	2623 ceramic insulators and insulating fittings	159	2921 furnaces and furnace burners
112	2624 technical ceramic wares	160	2922 lifting and handling equipment
113	2625 ceramic articles n.e.c.	161	2923 non-domestic cooling and ventilation equipment
114	2626 refractory ceramic goods	162	2924 other general purpose machinery n.e.c.
115	2630 ceramic tiles and flags	163	2931 agricultural tractors
116	2640 bricks, tiles and construction products, in baked clay	164	2932 other agricultural and forestry machinery
117	2651 cement	165	2940 machine-tools
118	2652 lime	166	2941 portable hand held power tools
119	2653 plaster	167	2942 other metalworking machine tools
120	2661 concrete products for construction purposes	168	2943 other machine tools n.e.c.
121	2662 plaster products for construction purposes	169	2951 machinery for metallurgy
122	2663 ready-mixed concrete	170	2952 machinery for mining, quarrying and construction
123	2664 mortars	171	2953 machinery for food, beverage and tobacco processing
124	2665 articles of fibre cement	172	2954 machinery for textile, apparel and leather production
125	2666 other articles of plaster, concrete or cement	173	2955 machinery for paper and paperboard production
126	2670 monumental or building stone and articles thereof	174	2956 other special purpose machinery n.e.c.
127	2681 abrasive products	175	2960 weapons and ammunition
128	2682 other non-metallic mineral products n.e.c.	176	2971 electric domestic appliances
129	2710 basic iron and steel and ferro-alloys (ecsc)	177	2972 non-electric domestic appliances
130	2721 tubes and tube fittings, of cast iron	178	3001 office machinery and parts thereof
131	2722 steel tubes and steel tube fittings	179	3002 computers and other information processing equipment
132	2731 cold drawn products	180	3110 electric motors, generators and transformers
133	2732 cold-rolled of narrow strips	181	3120 electricity distribution and control apparatus
134	2733 cold formed or folded products of iron, non-alloy steel or stainless steel	182	3130 insulated wire and cable
135	2734 wire	183	3140 accumulators, primary cells and primary batteries
136	2735 ferro-alloys (non-ecsc) and other iron and steel n.e.c.	184	3150 lighting equipment and electric lamps

Source: own elaboration from COMEXT database.

Appendix A. (Continuation) COMEXT products considered

Prod. Num.	COMEXT code, Product	Prod. Num.	COMEXT code, Product
185	3161 electrical equipment for engines and vehicles n.e.c.	202	3542 bicycles
186	3162 other electrical equipment n.e.c.	203	3543 invalid carriages
187	3210 electronic valves and tubes and other electronic components	204	3550 other transport equipment n.e.c.
188	3220 television and radio transmitters, apparatus for line telephony and telegraphy	205	3611 chairs and seats
189	3230 television and radio receivers, sound or video recording or reproducing apparatus and associated goods	206	3612 other office and shop furniture
190	3310 medical and surgical equipment and orthopaedic appliances	207	3613 kitchen furniture
191	3320 instruments and appliances for measuring, checking, testing, navigating and other purposes	208	3614 other furniture
192	3340 optical instruments and photographic equipment	209	3615 mattresses
193	3350 watches and clocks	210	3621 coin and medals
194	3410 motor vehicles	211	3622 jewellery and related articles n.e.c.
195	3420 bodies (coachwork) for motor vehicles; trailers and semi-trailers	212	3630 musical instruments
196	3430 parts and accessories for motor vehicles and their engines	213	3640 sports goods
197	3511 ships	214	3650 games and toys
198	3512 pleasure and sporting boats	215	3661 imitation jewellery
199	3520 railway and tramway locomotives and rolling stock and parts thereof	216	3662 brooms and brushes
200	3530 aircraft and spacecraft	217	3663 other manufactured goods n.e.c.
201	3541 motorcycles		

Source: own elaboration from COMEXT database.

Appendix B. Computing deflators

To compute tariffs based on avoided emissions the analysis has to consider that usually the same product produced in different countries has different prices. We consider the EU as a single region. We compute the emissions that EU would produce if it had produced domestically its imports, that is the avoided emissions. Once we obtain them, we need to apply a deflator for each product and each country to take into account international differences in prices. The deflator d_k^r of product k that the EU imports from country r is equal to the ratio between the domestic price of k in the EU and the price of the same good produced abroad and imported by the EU $d_k^r = p_k^s / p_k^r$, being s the EU.

We obtain data on prices from the COMEXT database (Eurostat, 2015) that contains information on imports/exports to/from the EU in both monetary and physical terms. We obtain the prices of the imported product p_k^r. By dividing the value of a product imported in Europe from a foreign country over its quantity. Regarding the domestic price of the EU product p_k^s we compute the price of the products exported from EU, and we assume that the price of products exported from EU is the same as the domestic price of EU products, because data in physical terms are available only for international trade flows.

By using data in monetary and physical terms from COMEXT, the prices obtained are the ones implicit in COMEXT database. Since the deflators are then applied to WIOD import data, we assume that prices in the two databases are the same.[19] There are two reasons to use data in monetary and physical terms from COMEXT. First, it records imports in "Cost, Insurance and Freight" (CIF) prices and exports in "Free On Board" (FOB) prices. Since also WIOD uses CIF and FOB prices, assuming that prices are the same seems to be realistic. Second, using data in monetary terms from COMEXT has a further advantage since data are more disaggregated than in WIOD. We indeed use information of 217 COMEXT products to compute the deflator for the 22 WIOD products the analysis is focused on.

Indeed using aggregated data could cause a bias in the deflators computed, just because the relative weight of different sub-products belonging to the same aggregate category is different. Let us consider a simplified numerical example, where EU exports and imports two different manufactured food products, yogurt and wine, with a non-EU country. Let us also assume that, while European yogurt exported is twice as expensive as the imported yogurt (P_y^E=4, P_y^I=2), the price of a bottle of wine is the same (P_w^E = P_w^I =10). Finally, let imagine that Europe exports 10 units of yogurt and 10 bottles of wine (Q_y^E=10, Q_w^E=10) and imports 50 units of yogurt and 10 bottles of wine (Q_y^I=50, Q_w^I=10). The values of exported and imported goods are indeed: V_y^E=40, V_w^E=100, V_y^I=100, V_w^I=100. If data on values and quantities available are disaggregated, dividing the values over the quantities of yogurt and wine exported and imported we obtain the original prices, and the deflators obtained are equal to 2 for yogurt, 1 for wine. If data on values and quantities for the two products are instead aggregated (V^E=140, V^I=200, Q^E=20, Q^I=60), we would obtain a price for the unique good exported (P^E=7) and a price for the unique product imported (P^I=3.3) biased by the relative weight of each product, resulting in a deflator equal to 2.1, which would be greater than the highest deflator obtained with disaggregated data.

So, to compute a deflator for each WIOD product, we compute prices of imports and exports with the highest disaggregation possible using COMEXT data, and then we aggregate in a single price for each WIOD category weighting the prices for the quantities imported. In the previous numerical example, we would obtain an "adjusted" aggregated price of export $P^E_{adjusted}$ equal to 5, an "adjusted" aggregated price of import $P^I_{adjusted}$ equal to 3.3, and a deflator equal to 1.5.[20] Formally, adjusted prices are computed as:

$$P_{Adjusted}^E = \frac{P_y^E * Q_y^I + P_w^E * Q_w^I}{Q_y^I + Q_w^I} = 5$$

and

$$P_{Adjusted}^I = \frac{P_y^I * Q_y^I + P_w^I * Q_w^I}{Q_y^I + Q_w^I} = 3.3$$

[19] An alternative method can be to use data in monetary terms from WIOD. This implies finding directly the prices of the WIOD database, but assuming that the quantities recorded in the two databases are the same.

[20] An alternative way would be, inversely, to adjust the import price for the quantities exported. We choose the first alternative because the deflators obtained are then applied to adjust products imported by Europe.

Appendix C. Deflators.

		AUS	BRA	CAN	CHN	IDN	IND	JPN	KOR	MX	RUS	TUR	TWN	USA	ROW
15	Food products and beverages	1.3	2.1	0.6	0.8	2.3	1.0	0.4	0.6	1.0	2.2	0.9	1.5	1.1	1.3
16	Tobacco products*	1.0	3.0	0.6	0.7	4.9	3.8	1.8	1.3	0.6	1.3	0.9	1.0	1.1	2.9
17	Textiles	1.0	1.7	2.1	3.0	3.7	2.4	0.7	1.8	1.7	2.9	2.1	2.2	1.2	2.9
18	Wearing apparel	1.0	1.6	0.6	2.2	1.5	2.1	0.3	2.0	0.9	1.2	1.4	2.5	1.0	1.9
19	Leather and leather products	3.5	1.8	1.9	5.3	2.1	2.2	0.5	1.3	1.6	2.9	2.4	2.8	2.1	2.1
20	Wood and products of wood and cork	1.1	1.0	1.2	1.2	0.8	1.0	0.3	0.4	0.4	1.8	0.8	0.5	0.8	1.3
21	Pulp, paper and paper products	1.0	1.1	0.9	0.7	0.8	0.8	0.2	0.6	1.0	1.0	1.1	0.4	0.7	0.9
22	Printed matter and recorded media	0.8	0.7	0.6	2.7	3.7	3.2	0.4	2.0	0.5	1.0	2.1	1.1	0.8	1.6
23	Coke, refined petroleum products	5.3	1.4	1.6	0.6	0.9	0.9	0.9	0.9	8.7	1.1	0.8	1.0	1.5	1.0
24	Chemicals, chemical products	0.9	3.2	1.2	2.3	7.4	2.2	0.4	2.0	2.1	3.0	2.4	1.5	0.8	1.4
25	Rubber and plastic products	0.7	1.0	1.1	1.9	1.5	1.8	0.6	1.1	0.9	0.9	1.4	1.2	0.6	1.4
26	Other non-metallic mineral products	0.5	1.3	1.5	2.7	2.1	1.6	0.3	0.5	1.1	2.7	1.7	1.5	0.4	2.2
27	Basic metals	0.4	0.9	0.2	1.4	0.4	1.4	0.5	0.7	1.0	1.1	1.6	1.1	0.7	0.6
28	Fabricated metal products	0.8	1.6	0.9	2.6	1.9	2.5	0.8	1.8	1.2	2.5	2.1	2.3	0.5	1.2
29	Machinery and equipment n.e.c.	0.9	1.9	0.7	2.9	2.3	2.4	0.9	1.9	1.1	2.0	2.5	2.0	0.8	1.0
30	Office machinery and computers	0.4	0.9	0.6	1.4	3.1	2.4	0.7	0.7	0.7	0.6	1.3	0.9	0.8	0.9
31	Electrical machinery	0.4	2.4	0.4	2.2	2.0	2.4	0.6	1.2	0.8	2.0	2.2	0.9	0.4	1.1
32	Radio, television and comm. eq.	1.4	2.7	0.7	2.9	1.5	4.5	1.5	1.1	0.8	1.7	2.2	1.4	1.3	2.2
33	Medical and optical instruments	0.6	2.5	1.0	8.4	1.6	3.7	1.0	2.6	1.6	0.4	6.2	3.1	0.8	1.0
34	Motor vehicles, trailers	0.7	1.2	1.0	2.7	1.4	1.6	0.9	1.5	1.0	1.7	1.2	1.5	0.9	1.3
35	Other transport equipment	1.7	1.0	1.4	1.8	3.6	2.5	1.1	0.3	2.6	5.1	1.4	1.5	1.3	0.7
36	Furniture; other manufactured goods	0.2	13.4	0.6	2.5	2.4	1.4	0.6	1.6	1.8	1.1	1.8	1.9	1.1	1.7

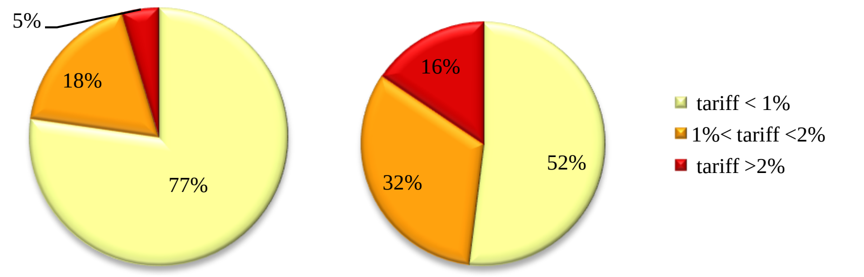
Source: own elaboration on COMEXT and WIOD databases.

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; USA: United States; ROW: Rest of the World.

* The category "tobacco products" has been adjusted using additional more disaggregated data from the COMEXT database "EU Trade Since 1988 By SITC", following the nomenclature correspondence provided by Eurostat in the database RAMON available at http://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL.

Appendix D. Tariffs on avoided emissions: monetary terms.

Figure D1. Percentage of products based on their tariff size, with CBTA computed on avoided emission



a. Avoided emissions (monetary) **b. Avoided emissions (adjusted for price differences)**

Source: own elaboration.

In a CBTA system calculated on avoided emissions (Figure G1.a) among products that would be more strongly affected through tariffs higher than 2% would be 5%, and products with tariffs between 1% and 2%would be the 18%.. Adjusting for price differences (Figure A1.b) reveals that the most polluting products – or the products produced by the most polluting countries - are, on average, cheaper than European products, that implies that, after deflating data, the percentage of products strongly affected would be higher compared with the percentage found without adjusting for price differences (16% instead of 5%). Also mildly affected products, as the strongly affected ones, would be proportionally more when adjusting for price differences (32% instead of 18%). This result reveals that is necessary to take into account international price differences to avoid biased outcomes.

Table D1. CBTA by product for any non-EU country, in percentage, corresponding to a 20 euro/ CO_2 tonne European carbon tax

		CBTA AE^{*}	CBTA AE_d^{**}													
			AUS	BRA	CAN	CHN	IDN	IND	JPN	KOR	MEX	RUS	TUR	TWN	USA	ROW
15	Food products and beverages	0.8	1.0	1.6	0.5	0.6	1.8	0.8	0.3	0.5	0.8	1.7	0.7	1.2	0.9	1.0
16	Tobacco products	0.8	0.8	2.3	0.4	0.5	3.8	3.0	1.4	1.0	0.5	1.0	0.7	0.8	0.9	2.2
17	Textiles	0.7	0.7	1.2	1.5	2.1	2.5	1.6	0.5	1.3	1.2	2.0	1.4	1.5	0.8	2.0
18	Wearing apparel	0.7	0.7	1.0	0.4	1.5	1.0	1.4	0.2	1.4	0.6	0.8	0.9	1.7	0.7	1.3
19	Leather and leather products	0.5	1.8	0.9	0.9	2.6	1.0	1.1	0.3	0.7	0.8	1.4	1.2	1.4	1.1	1.1
20	Wood and products of wood and cork	0.7	0.8	0.8	0.9	0.9	0.6	0.7	0.2	0.3	0.3	1.3	0.6	0.4	0.6	0.9
21	Pulp, paper and paper products	0.7	0.7	0.8	0.7	0.5	0.6	0.6	0.1	0.5	0.7	0.7	0.8	0.3	0.5	0.7
22	Printed matter and recorded media	0.7	0.6	0.5	0.4	1.9	2.6	2.3	0.3	1.5	0.3	0.7	1.5	0.8	0.5	1.2
23	Coke, refined petroleum products	1.9	10.2	2.8	3.2	1.2	1.7	1.8	1.8	1.8	16.8	2.0	1.6	1.9	2.9	2.0
24	Chemicals, chemical products	1.1	1.0	3.5	1.3	2.5	8.1	2.4	0.4	2.2	2.3	3.3	2.6	1.6	0.8	1.5
25	Rubber and plastic products	0.7	0.5	0.7	0.8	1.4	1.1	1.3	0.4	0.8	0.6	0.7	1.0	0.9	0.4	1.0
26	Other non-metallic mineral products	2.9	1.4	3.6	4.4	7.6	6.1	4.7	0.7	1.6	3.3	7.8	4.9	4.2	1.3	6.4
27	Basic metals	1.2	0.5	1.1	0.3	1.7	0.5	1.7	0.6	0.9	1.2	1.3	2.0	1.3	0.9	0.7
28	Fabricated metal products	1.2	1.0	1.9	1.1	3.2	2.3	3.0	0.9	2.2	1.4	3.0	2.6	2.9	0.7	1.5
29	Machinery and equipment n.e.c.	0.6	0.5	1.1	0.4	1.7	1.3	1.4	0.5	1.1	0.7	1.2	1.4	1.1	0.5	0.6
30	Office machinery and computers	0.5	0.2	0.4	0.3	0.7	1.4	1.1	0.3	0.3	0.3	0.3	0.6	0.4	0.4	0.4
31	Electrical machinery	0.5	0.2	1.3	0.2	1.2	1.0	1.3	0.3	0.6	0.4	1.1	1.2	0.5	0.2	0.6
32	Radio, television and comm. eq.	0.5	0.7	1.3	0.4	1.4	0.7	2.2	0.7	0.5	0.4	0.8	1.0	0.7	0.6	1.1
33	Medical and optical instruments	0.5	0.3	1.2	0.5	4.2	0.8	1.9	0.5	1.3	0.8	0.2	3.1	1.6	0.4	0.5
34	Motor vehicles, trailers	0.6	0.4	0.7	0.6	1.6	0.8	0.9	0.5	0.9	0.6	1.0	0.7	0.9	0.5	0.8
35	Other transport equipment	0.6	1.0	0.6	0.9	1.1	2.2	1.5	0.6	0.2	1.6	3.1	0.8	0.9	0.8	0.4
36	Furniture; other manufactured goods	0.7	0.2	8.7	0.4	1.6	1.6	0.9	0.4	1.0	1.2	0.7	1.2	1.2	0.7	1.1

Source: own elaboration.
Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; USA: United States; ROW: Rest of the World.
* Carbon border tax calculated on the emissions avoided by Europe through trade.
**Carbon border tax calculated on the emissions avoided by Europe through trade, adjusting for international prices differences.