Accounting for embodied emissions in international trade: physical vs monetary trade flows

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Abstract

The Domestic Technology Assumption (DTA) allows estimating emissions embodied in trade when full multiregional input-output tables are not available or are not useful due to the scope of the analysis. The usual way to apply the DTA is considering that emissions per monetary value unit of each sector in any country are the same that in the country analyzed ('monetary DTA'). In this paper we show that a 'physical DTA' would be the appropriated approach when there are differences of prices between countries. We have applied both methodologies (monetary and physical DTA) to the analysis of GHG emissions in Spain 2000. Both methodologies show that Spain is a 'net emission exporter' and, in consequence, its responsibility in emissions as a 'consumer' is higher than as a 'producer'. The difference between both types of responsibilities increases when applying the 'physical DTA'. That is in a great way due to the fact that the 'monetary DTA' estimates less embodied emissions in imports from non-Annex I countries than the 'physical DTA'.

Keywords: International trade, Atmospheric pollutants, Interregional input-output model.

Topic: 6.- International Trade.

1. Introduction

In recent years, there has been an increasing interest in estimating the 'emission trade balance' of countries. This interest has been preceded by a growing concern about political implications of production-based and consumption-based accounting principles. As we will see in this paper, the importance of the distinction between the two approaches is undoubtedly relevant for environmental policy both for emissions with local/regional impact and for global pollutants.

In the literature it has been widely recognized that the proper way to estimate emission trade balance and to analyze the so-called 'producer' and 'consumer' responsibilities is to apply an environmental extended multiregional input-output model (MRIO) (Minx et al. 2009). This methodology not only takes into account direct and indirect emissions associated with the exports and/or imports, but it also allows for considering different technologies of regions or countries. The empirical application of these models requires the use of multiregional input-output tables; however, at this moment the existence of such tables are rare and the use of some available database are not exempt of drawbacks[1]. Thus, many studies have applied the so-called 'Domestic Technology Assumption' (DTA), which supposes that the technology (and associated emissions) of different economic sectors in the rest of the world is the same as in the country analyzed.[2]

The DTA hypothesis is obviously very restrictive but it is accepted that, under certain circumstances, it can be a proper approximation to estimate emissions embodied in imports. For instance, MRIO tables are basically a compilation of input-output tables from individual countries. Usually these databases are considerably outdated due to the delay on the publication of some country data and because of the time needed to

[1] There are interesting works using the Global Trade Analysis Project (GTAP) database (e.g. Peters and Hertwich, 2008; Andrew *et al.*, 2009; Wilting and Vringer, 2009; Muñoz and Steininger, 2010). This database, however, presents some inconsistencies and problems (Peters and Hertwich, 2008). Nevertheless, it is expected an improvement on database availability due to two recent EU-funded projects EXIOPOL and WIOD focused on constructing multi-country and inter-country input-output tables, respectively.

[2] Some examples are Walter (1973), Proops *et al.* (1993), Kondo *et al.* (1998), Munksgaard and Perdersen (2001), Machado *et al*. (2001), Tolmasquim and Machado (2003), Sánchez-Chóliz and Duarte (2004),

harmonize the different tables. Therefore, if individual country data is more up to date than multiregional data and if this is relevant in order to answer some policy questions a DTA model could be preferred. Moreover, while MRIO approach is more precise than DTA approach, the cost and work effort is substantially greater in building MRIO databases. Consequently, there is a trade-off between accuracy and costs. In addition, sometimes the disaggregation or breakdown of multiregional data is not sufficient to answer some specific policy questions. Thus, if individual country data is more disaggregated a DTA model could be preferred over a MRIO model. Another case in which the application of the DTA would be justified is when the study is aimed at measuring the avoided emissions owing to the fact that a country imports commodities from abroad instead of producing them into the country.[3]

In this paper, however, we will discuss that the DTA applied to emissions could be much more restrictive that it seems in principle. In fact, the so-called DTA is indeed a 'worth' or 'value' assumption, which considers that the emissions per value unit of output of each sector is the same in the rest of the world as in the country analyzed. The 'monetary DTA' (as we will call it from now on) is even more restrictive than the assumption of identical production techniques because it implicitly assumes that prices (translated into common currency when necessary) of imported and exported commodities are the same. Assuming identical prices in this context might break one of the motivations of international trade. Therefore, in this paper we will define an alternative assumption called 'physical DTA'. This approach assumes that each sector in the country analyzed and abroad has the same emissions per physical unit of output and, consequently, it implies to use physical data of sectorial imports and exports. As an empirical illustration, we will estimate the emission trade balance of greenhouse gas (GHG) emissions in Spain 2000 using both methodological approaches and we will compare the results.

The structure of the paper is as follows. Section 2 explains the relevance for environmental policy of adopting the 'producer' versus the 'consumer' perspective. In

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Mongelli *et al.* (2006), Mukhopadhyay and Chakrabory (2005), Dietzenbacher and Mukhopadhyay (2007), and Tunç *et al.* (2007).

Section 3, we explain in detail the differences and implications between the 'monetary DTA' and 'physical DTA' and we present the methodology considered in this paper. In Section 4 results for Spain 2000 are analyzed. Finally, conclusions are presented in Section 5.

2. Environmental policy implications of producer and consumer perspectives

Significant attention has been given to achieve a better understanding of environmental pressures generated by an economy taking into account international trade at the national level. One of the most well-studied aspects has been the differentiation between the 'producer' and 'consumer' responsibilities (Proops *et al.*, 1993; Steenge, 1999; Munksgaard and Pedersen, 2001) or the production-based and consumption-based accounting principles (Peters, 2008).

According to the first principle a country would be responsible for all emissions generated inside its economic territory. This is the so-called 'producer' responsibility perspective adopted by official statistics on pollution (such as national emission inventories requested by the United Nations Framework Convention on Climate Change) and by international agreements as the Kyoto protocol. Usually, however, some of the commodities produced by a country are consumed abroad as well some of its consumption has been produced by a foreign country. In that case, accounting emissions according to the consumption-based principle would imply to consider all the emissions generated inside a country adding emissions associated with imports and subtracting emissions associated with exports. This is the 'consumer' responsibility perspective even though 'domestic demand' or 'final user' responsibility would be more appropriated since investment is also part of the domestic demand.[4] Naturally, comparing the 'consumer' responsibility and the 'producer' responsibility of a country is equivalent to calculating its 'emission trade balance' (Weidema et al., 2006; Peters and Hertwich, 2008, Serrano and Dietzenbacher, 2010). That is, if embodied

[3] According to Andrew *et al.* (2009) the estimations applying a MRIO model using the DTA and GTAP database differ considerably; however, "for some countries [Korea, Spain, Brazil, and Canada] the results using the DTA are excellent" (p. 316.

[4] Some authors also use the term "carbon footprint" (see special issue of *Economic System Research*, 2009, volume 21(3); and the articles of Wiedmann, 2009; Minx *et al.*, 2009).

emissions in imports are higher than those in exports, ‘consumer’ emissions will be higher than ‘producer’ emissions and the country will be a ‘net exporter’ of emissions.

The distinction between the two types of responsibilities is greatly relevant to environmental policy both for emissions with local/regional impact and for global pollutants. On the one hand, local/regional impacts will be associated with an ‘environmental cost shifting’ or ‘environmental load displacement’ as suggested Muradian and Martínez-Alier (2001). According to these authors, by importing goods and services the country could benefit from the consumption of such commodities without supporting the negative environmental costs associated to its production. This is one of the aspects related with the ‘ecological debt’ concept (Martinez-Alier, 1993; Torras, 2003), which states that rich countries have a debt to poor countries due to environmental degradation suffered by the latter in order to provide cheap commodities to rich countries. Moreover, the Environmental Kuznets curve’s debate has also given a significant attention to this question since the decoupling between economic growth and environmental degradation that the empirical evidence shows in some periods for some very specific pollutants and for some countries might rise not from a genuine improvement but from displacing pressures to other territories when trade is taking into account (Arrow *et al.*, 1995; Stern *et al.*, 1996).

On the other hand, the distinction between both types of responsibilities regarding global impacts connects with the outstanding political debate about how to evaluate the relative contribution of different countries to a global problem, such as global warming, and with the effectiveness of international agreements. As a result, in international meetings about future compromises in limiting GHG emissions some countries have convincingly maintained not only that their per capita emissions are very low in comparison with per capita emissions of richest countries, but also that a great part of their emissions are generated when producing the commodities exported to other countries. This was, for instance, the stand of China in the United Nations Climate Change Conference held in December 2009 in Copenhagen. In addition, when an international agreement on emissions only affect to some countries, such as the Kyoto protocol, the regulated countries (known as Annex-I countries) could accomplish its national targets by ‘exporting’ emissions to other countries that have not limitations established by the agreement (non Annex-I countries). This possibility, pointed out by Wyckoff and Roop (1994) years before the Kyoto Protocol was established, has been called ‘carbon leakage’.

Consequently, the estimation of emissions from the ‘consumer responsibility’ and, hence, of the ‘emission trade balance’ for different countries are two key issues of policy relevance, which also justified the increasing academic interest in this field.

3. Methodology

3.1 Discussion: ‘monetary DTA’ versus ‘physical DTA’

While estimations of embodied pollution in international trade have been done since the 1970’s, it remains of active interest due to the growth on international trade, which could hide the responsibility of different countries in environmental problems and specifically in climate change. As mentioned in the introduction, the most suitable perspective to analyze this issue is the well-known input-output approach and specifically the environmental extended MRIO models. However, due to the data availability or due to the scope of the analysis some studies have applied the ‘monetary DTA’. This hypothesis is much more restrictive than the usual critics establish because it implies not only same technologies but also same prices, which is not very plausible in trade.

As a matter of fact, divergences between emissions embodied in imports and exports depend not only on different technologies, on the trade balance of each country, and on the structure of trade; but also on the different prices of tradable commodities. In other words, assuming for simplicity that countries have the same technology, the important aspects are not only the trade deficit (e.g. United States or Spain) or surplus (e.g. China) that a country has in its balance of trade, or if this country is specialized in importing or exporting relatively more or less polluting commodities; it also matters the difference of the commodity price when it is exported and/or imported, i.e. the relative price.

The relative price of each commodity in different countries is affected by many factors such as relative labor costs, fiscal pressures and/or the existence of subsidies.

Moreover, and even more important, the average level of prices (in a common currency) could be also very different. Changes in exchange rate affect the relation between emissions for unit of value even if techniques do not change. As a result, emissions embodied in imports calculated in the basis of the 'monetary DTA' could be misleading. Thus, it would be preferable to use physical trade data and to apply 'physical DTA' to get better results. An example to illustrate this case is the Spanish footwear sector. Spain consumes shoes produced inside the country and also shoes imported from China, which are considerable cheaper. In this case, even if the technologies were identical, the value of imports from China could imply much more emissions than the same value produced in Spain because the value of imports from China contains a higher physical quantity of shoes.

Therefore, from a theoretical view point, the 'physical DTA' would be better than the 'monetary DTA' because the former calculates embodied emissions in imports according to real quantities traded, leaving out of the analysis the effect of different prices.

As pointed out before, the 'monetary DTA' is much more restrictive because it implies assuming not only same technologies but also same prices. Thus, when for any reason it would be not possible to apply a full MRIO model and the DTA must be used, the estimations can be improved by substituting –when possible– monetary for physical data. In short, we could say that 'emission trade balance' depends on four factors: the balance of trade in monetary terms, the structure or composition of imports and exports, the relative prices between countries, and differences in technologies. The 'monetary DTA' only considers the two first factors, whereas the 'physical DTA' considers all the factors with the exception of the last, and the full MRIO model considers all of them. Therefore, we can conclude that when a full MRIO model is not applicable it is preferable the 'physical DTA' to the 'monetary DTA'.

However, things are more complex. One of the assumptions underlying input-output models is that each sector consists on an aggregation of 'units of homogeneous production'. When the 'DTA' (monetary or physical) is applied, the aggregation assumption means that each sector produces the same single product, wherever it is located. In reality, such 'units of homogeneous production' do not exist for the most part of sectors. On the empirical level, each sector could include a wide range of different products, which has implications for our analysis[5].An example of a sector with heterogeneous products is the sector of 'Paper'.

Let be the case of a country exporting paper sheets and importing paper pulp, both included in 'Paper' sector. Pulp is an input to produce paper sheets and emissions and value per tonne of paper sheets are higher than emissions and value per tonne of paper pulp. Here the differences would be determined by the relation between value added and emissions added in each stage of the product chain. However, this heterogeneity of products does not necessarily affect the argument. Frequently, where the greater pollution is generated and the less value is added is in the earlier stages of the production process of a sector (this would be the case of paper). Consequently, in such cases, the physical weight seems to be much more relevant than the monetary value to determining the relative emissions, i.e. the 'physical DTA' would be preferable than the 'monetary DTA'.

Obviously, we can not generalize the previous example and it would be possible that in some sectors and specific cases the 'monetary DTA' might be more appropriated than the 'physical DTA'. However, in general and when there is not additional information, we think that the second approach is a better option than the usual 'monetary DTA' not only in a theoretical case (as we have demonstrated) but also in empirical analysis.

3.2 Model of a small country applying the 'monetary DTA'

In this model we consider one country (r = 1) and the rest of the world (r = 2). The n sectors of country 1 produce n products that can be sold as intermediate inputs or as final commodity to final users. Since country 1 is an open economy its production is consumed inside the country and/or abroad. The accounting equations would be $\mathbf{x} = \mathbf{Zi} + \mathbf{y}$ or in its partitioned form as[6]

[5] In any case, this is a general limitation of empirical analysis of the theoretical input-output model. This shortcoming could be more or less important depending on the level of disaggregation, i.e. the number of different sectors considered. Wood and Dey (2009) depicts Australia's case applying the 'monetary DTA' considering 344 sectors.

[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

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{Z}^1 & \mathbf{S}^1 \\ \mathbf{S}^2 & \mathbf{Z}^2 \end{bmatrix} \begin{pmatrix} \mathbf{i} \\ \mathbf{i} \end{pmatrix} + \begin{pmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{pmatrix} \quad (1)$$

where $\mathbf{i}$ is the column summation vector (i.e. entirely consisting of ones) of appropriate length. With $r = 1, 2$, vectors $\mathbf{x}^r$ are the output of each region, matrices $\mathbf{Z}^r$ indicate the transactions of intermediate inputs within each region, $\mathbf{S}^r$ indicate the transactions of intermediate inputs that come from abroad (imported intermediate inputs), $\mathbf{h}^r$ represent domestic final demand, and $\mathbf{e}^r$ gives the imports by final users.

The input coefficients are obtained from $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$ which can be partitioned in the same way as $\mathbf{Z}$. In that case, $\mathbf{A}^r$ are matrices of domestic input coefficients, and $\mathbf{M}^r$ are coefficient matrices for the imported inputs. The accounting equation can now be written as $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$, or in its partitioned form as

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{A}^1 & \mathbf{M}^1 \\ \mathbf{M}^2 & \mathbf{A}^2 \end{bmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} + \begin{pmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{pmatrix} \quad (2)$$

In this model we analyze the particular case of a small country that trades with the rest of the world. Although exports of the small country are obviously non-zero, they will be negligible when compared to the output of the rest of the world. Thus it seems plausible to assume that $\mathbf{M}^1 = 0$.

The second feature of this case is quite common in the literature when full multiregional input-output tables are not available or are not useful because of different reasons. Thus, it is assumed that production technology is the same in the country and in the rest of the world, i.e. the so-called 'monetary DTA'. We can now simplify the notation, so that equation (2) becomes

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{A} & 0 \\ \mathbf{M} & \mathbf{A} + \mathbf{M} \end{bmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} + \begin{pmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{pmatrix} \quad (3)$$

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.

The solution of this model is given by $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$ that in its partitioned form has the following expression

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} (\mathbf{I}-\mathbf{A}) & 0 \\ -\mathbf{M} & (\mathbf{I}-\mathbf{A}-\mathbf{M}) \end{bmatrix}^{-1} \begin{pmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{pmatrix} \tag{4}$$

In order to estimate emissions associated with the production of each region we define the matrix of atmospheric emission coefficients $\mathbf{V}^r$. Applying the 'monetary DTA' it also implies assuming the same emission intensities in both regions ($\mathbf{V}^1 = \mathbf{V}^2 = \mathbf{V}$). Thus, the emissions generated in each region are given by

$$\begin{pmatrix} \mathbf{G}^1 \\ \mathbf{G}^2 \end{pmatrix} = \begin{pmatrix} \mathbf{V}\mathbf{x}^1 \\ \mathbf{V}\mathbf{x}^2 \end{pmatrix} = \begin{pmatrix} \mathbf{V} \\ \mathbf{V} \end{pmatrix} \begin{bmatrix} (\mathbf{I}-\mathbf{A}) & \mathbf{0} \\ -\mathbf{M} & (\mathbf{I}-\mathbf{A}-\mathbf{M}) \end{bmatrix}^{-1} \begin{pmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{pmatrix} \tag{5}$$

From equation (5) we calculate embodied emissions in exports ($\mathbf{gexp}^r$) and in imports ($\mathbf{gimp}^r$). For region 1 we have

$$\mathbf{gexp}^1 = \mathbf{V}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{e}^1 + \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{e}^1 \tag{6}$$

$$\mathbf{gimp}^1 = \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}(\mathbf{h}^1 + \mathbf{e}^1) + \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{e}^2 \tag{7}$$

Defining the emission trade balance for region 1 ($\mathbf{etb}^1$) as the difference between the emissions embodied in exports and in imports, we have

$$\mathbf{etb}^1 = \mathbf{V}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{e}^1 - \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{h}^1 - \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{e}^2 \tag{8}$$

Following Serrano and Dietzenbacher (2010), at aggregate level of emissions we can simplify equation (8) as

$$\mathbf{etb}^1 = \mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}(\mathbf{exp}^1 - \mathbf{imp}^1) \tag{9}$$

Where $\mathbf{exp}^1$ is the vector of total value of exports of country 1, i.e. $\mathbf{exp}^1 = \mathbf{e}^1$, and $\mathbf{imp}^1$ is the vector of total value of imports of country 1.

3.3 Applying the 'physical DTA'

From equation (9) it is easy to see that total emissions embodied per value unit of imports of each sector are the same as total emissions embodied per value unit of exports, i.e. $\mathbf{V}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}$. In other words, the total multiplier of emission intensity per value unit of exports or imports is the same in both regions

$$\frac{\mathbf{gexp}^1}{\mathbf{exp}^1}=\frac{\mathbf{gimp}^1}{\mathbf{imp}^1} \tag{10}$$

Note that in this model $\mathbf{exp}^1$ and $\mathbf{imp}^1$ represent total value of exports and total value of imports of region 1, respectively. Therefore, we can rewrite total value of exports of region 1 $\mathbf{exp}^1$ as the element-by-element multiplication (denoted by $\bullet$) of two vectors: the vector of unit prices of exports of region 1 ($\mathbf{p}^1$) and the vector of quantities of exports of region 1 ($\mathbf{q}^1$), i.e. $\mathbf{exp}^1=\mathbf{p}^1\bullet\mathbf{q}^1$. In the same way, we can rewrite the vector of total value of imports of region 1 as $\mathbf{imp}^1=\mathbf{p}^2\bullet\mathbf{q}^2$. Where $\mathbf{p}^2$ is the vector of unit prices of exports of region 2, and $\mathbf{q}^2$ is the vector of quantities of exports of region 2.

As mentioned above, the 'monetary DTA' implies assuming that both regions have not only the same technology but also same prices of tradable commodities ($\mathbf{p}^1=\mathbf{p}^2$). Therefore, in the supposition of a country in which $\mathbf{exp}^1=\mathbf{imp}^1$ this would imply that $\mathbf{q}^1=\mathbf{q}^2$ and, due to DTA, embodied emissions in imports and exports would be the same.

However, prices of imports and exports might differ considerably between regions for several reasons. Allowing for different prices, i.e. $\mathbf{p}^1\neq\mathbf{p}^2$, we can easily imagine the case of a country with $\mathbf{exp}^1=\mathbf{imp}^1$ but different emissions embodied in exports and imports because the quantity exported and the quantity imported is different, i.e. $\mathbf{q}^1\neq\mathbf{q}^2$. In such cases, the application of the 'monetary DTA' might be misleading and it would be recommended to apply the 'physical DTA'.

The ‘physical DTA’ assumes that the total multiplier of emission intensity per physical unit of exports or imports is the same in both regions, but not per value unit. In order to introduce the ‘physical DTA’ into the previous model we deflate prices of country 1’s imports to prices of exports of the same country. This yields for each sector *j* (*j* = *1…n*)

$$\tilde{imp}_j^1 = q_j^2 \frac{exp_j^1}{q_j^1} \quad (11)$$

Then if we divide the deflated imports by the value of imports we obtain the rate that allow us to correct all imports regardless if they are used as intermediate inputs or final products. Thus

$$\delta_j = \frac{\tilde{imp}_j^1}{imp_j^1} \quad (12)$$

Applying this rate we can define the coefficient matrix for the imported inputs for the ‘physical DTA’ as $\tilde{\mathbf{M}} = \hat{\delta}\mathbf{M}$. Thus, the emissions embodied in exports and imports according to the ‘physical DTA’ are now

$$\tilde{\mathbf{gexp}}^1 = \mathbf{V}(\mathbf{I} - \mathbf{A} - \tilde{\mathbf{M}})^{-1}\mathbf{exp}^1 \quad (13)$$

$$\tilde{\mathbf{gimp}}^1 = \mathbf{V}(\mathbf{I} - \mathbf{A} - \tilde{\mathbf{M}})^{-1}\tilde{\mathbf{imp}}^1 \quad (14)$$

4. Database and Results

We have applied the model to estimate embodied GHG emissions in Spanish international trade for the year 2000 using the DTA both in monetary and physical terms. The main data sources are domestic and imported symmetric input-output tables elaborated by the Spanish Statistical Institute (INE, 2009), Spanish atmospheric emissions satellite accounts (INE, 2006), and foreign trade statistics (Agencia Tributaria, 2009).

Input-output data have been aggregated to 46 sectors in order to match it with the sectorial classification of emission accounts. Foreign trade statistics offer annual information about flows of imports and exports, specifically: the country of origin and/or destination, weight and monetary value. The information on weights, obviously, is only available for primary and industrial sectors but not for services. This information has been used to correct imported symmetric input-output table for primary[7] and industrial sectors in order to apply the 'physical DTA'; and to share embodied emissions in trade by country according to their weight in total imports or exports by type of product. The last has been done using monetary or physical trade information depending on the hypothesis applied, i.e. the 'monetary DTA' or the 'physical DTA', respectively.

Table 1 shows the outcomes both applying the usual 'monetary DTA' and the alternative 'physical DTA' proposed in this paper. Analyzing the results from both hypotheses we find that embodied emissions in trade from the 'physical DTA' are nearly 15% higher for imports and 5% for exports. According to both approaches Spain in 2000 was a 'net emission exporter'. However, the difference between embodied emissions in imports and exports is significantly higher –nearly 37%– according the 'physical DTA'.

Table 1: Emissions embodied in trade, Spain 2000, MtCO2e

	Monetary DTA (3)	Physical DTA (4)	$\frac{(4)-(3)}{(4)}100$
Emissions embodied in imports (1)	218	250	14,8%
Emissions embodied in exports (2)	153	161	5,23%
Emission trade balance (2)-(1)	-65	-89	36,92%

Source: authors' elaboration.

As we have explained before the analysis of emissions linked to trade is relevant to differentiate between the 'producer responsibility' and the 'consumer responsibility'. Table 2 compares the outcomes according to the monetary and the physical approach, showing that emissions according to the 'consumer' perspective are higher with the 'physical DTA' than with the 'monetary DTA'.

[7] Due to limited representativeness of crude oil and gas extraction Spanish sector there is a high uncertainty on applying physical and monetary DTA to this sector. Furthermore, because of the relevance of crude oil and gas imports, the emission trade balance is very sensitive to the adoption of any of these

Table 2: GHG emissions from 'monetary DTA' and 'physical DTA', Spain 2000, MtCO2e

		Index number
'Producer responsibility'	364	100
'Consumer responsibility' according to 'monetary DTA'	429	117
'Consumer responsibility' according to 'physical DTA'	453	124

Source: authors' elaboration.
Note: These figures include the emissions from all the economic activities and also the household direct emissions.

From a geo-political perspective, it is also important to present results taking into account the origin and/or destination of imports and/or exports. In particular, considering the problem of carbon leakage pointed out in Section 2, it is interesting to disaggregate the emission trade balance with non-Annex I countries and with countries of Annex I of the Kyoto protocol. Table 3 shows that the greatest difference in the outcomes between monetary and physical approaches results in emissions embodied in imports from non-Annex I countries: these emissions are 25% lower applying the 'monetary DTA' than applying the 'physical DTA'. For Annex I countries this percentage is only 6%.

Table 3: Emissions embodied in primary and industrial sectors trade with Annex I and non-Annex I countries, Spain 2000, MtCO2e

	Annex 1 countries		**Non-Annex 1 countries**	
	Monetary DTA	**Physical DTA**	**Monetary DTA**	**Physical DTA**
Emissions embodied in imports (1)	135	144	68	91
Emissions embodied in exports (2)	108	111	21	25
Emission trade balance (2)-(1)	-27	-33	-47	-66

Source: authors' elaboration.
Note: embodied emissions in services are not included due to lack of information on origin/destiny. Therefore, the totals are lower than those of Table 1.

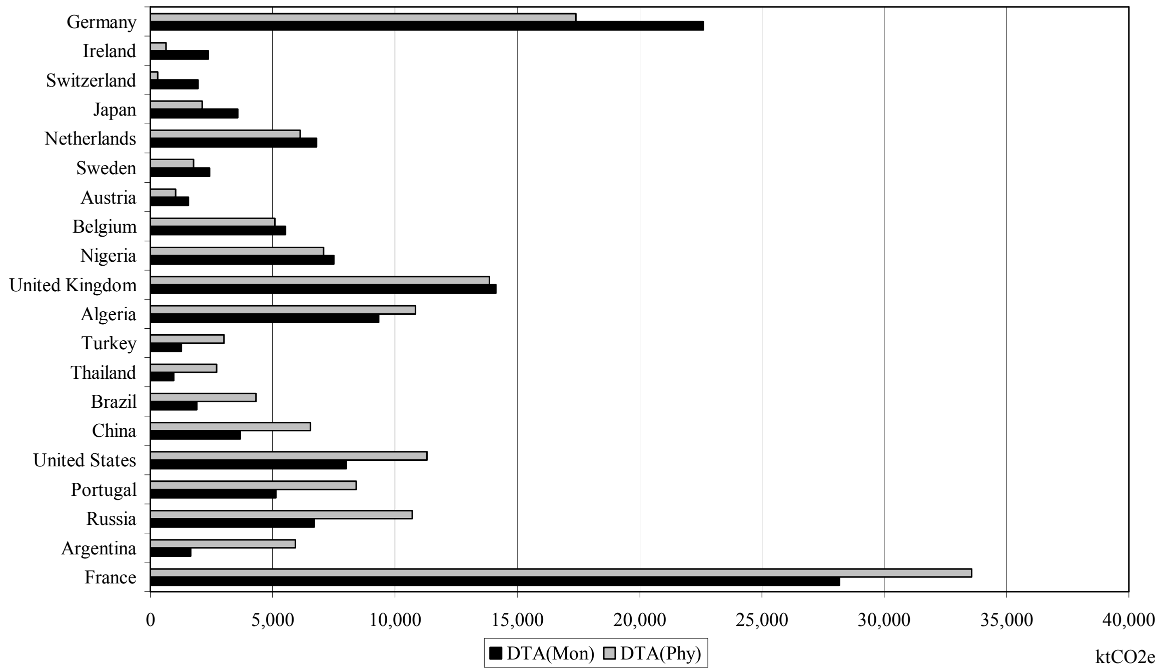
Country by country, the 'physical DTA' shows higher emissions embodied in imports than the 'monetary DTA' for 116 of 212 countries. In Fig. 1 we can see the most relevant countries in terms of imports. Within this group the higher differences (measured in MtCO2e) are found in France (5.4), Argentina (4.3), Russia (4.0), Portugal (3.3), United States (3.3), China (2.9), Brazil (2.4), Thailand (1.8), Turkey (1.7) and

approaches. Therefore, as in the case of services, only the usual 'monetary DTA' has been applied to this sector.

Algeria (1.5). These ten countries account for 65% of the total difference between the monetary and physical approach, and four of these countries are members of the OECD.

Regarding the countries for which emissions calculated applying the ‘monetary DTA’ are greater than the ones from the ‘physical DTA’, the ten countries with higher differences are (measured in MtCO2e): Germany (5.2), Ireland (1.7), Switzerland (1.6), Japan (1.5), Netherlands (0.7), Sweden (0.6), Austria (0.5), Belgium (0.4), Nigeria (0.4), and United Kingdom (0.2). These countries account for 90% of the total difference between both approaches and nine are OECD members.

Fig.1: Emissions embodied in imports by country, Spain 2000, $ktCO_2e$



Source: authors' elaboration.

5. Conclusions

The Domestic Technology Assumption (DTA) allows estimating emissions embodied in trade when full multiregional input-output (MRIO) tables are not available or are not useful due to the scope of the analysis. The usual way to apply the DTA is considering that emissions per monetary value unit of each sector in any country are the same that in the country analyzed (we call this approach 'monetary DTA'). We have shown that, assuming that a sector produces 'units of homogeneous production', a 'physical DTA' would be the appropriate approach when there are differences of prices between countries. However, in reality, each sector produces a wide range of products and therefore we cannot be completely sure that in empirical analysis the 'physical DTA' is a better approximation than the 'monetary DTA' for all the cases and sectors. Nevertheless, we think that the 'physical DTA' generally will give better outcomes than the 'monetary DTA' and, in any case, it is interesting to contrast both approaches.

We have applied both methodologies to the analysis of GHG emissions in Spain 2000 obtaining, as we expected, different outcomes. Both methodologies show that Spain is a 'net emission exporter' and in consequence its 'consumer responsibility' in emissions is higher than its 'producer responsibility'. The difference between both type of responsibilities increases applying the 'physical DTA' emissions and that is in a great way due to the fact that the 'monetary DTA' gives less embodied emissions in imports from non-Annex I countries than the 'physical DTA'.

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