Indirect Pollution Haven Hypothesis in a context of Global Value Chain

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Firms locate different stages of their production in third countries with the aim of reducing costs (labour, institutional, raw materials, etc. and also environmental costs), increasing their flexibility and, finally, generating growing economies of scale. This international fragmentation of production has led to a big increase in international trade of final goods and, particularly, intermediate inputs. This paper investigates whether there is a positive or negative link between value added provided by different countries to the global production chains and their environmental impact. In order to do this we develop a multi-region input-output model that allows us to isolate the different rounds or stages of production required by a good to reach final demand, and in this way, to calculate emissions generated by this product in several countries.

The impact on climate change from global value chains depends on three factors. First, technology used in the factory located in the emerging country. Second, differences in energy and environmental intensity that exist along the chain of suppliers between the countries of origin and destination. Third, increase in distance and international transport linked to the growth in international trade of these components (Cadarso *et al.*, 2010). A negative relationship between total value added and total CO_2 emissions linked to global production chains, and focused on emerging countries, will show a disconnection between economic and environmental costs. Firms would not take into account indirect costs on environment when making decisions on location or on origin of their suppliers, as they do not internalise these costs. This would support an indirect pollution haven hypothesis, as the fall in trade barriers would have implied a transformation of global production chains that, together with a growth in trade, would have boosted global emissions. This increase would not be due to using a technique that is directly less efficient in terms of emissions, but because of their linkage effects with production and emissions in the country of production/origin/destination and with the emissions linked to international freight transport.

1. Introduction

International freight transport has increased from 5.5% to 21% of worldwide GDP in 1950 in 2007 (WTO, 2008). A third of this international trade is due to the exchange of final goods, while the other two thirds are explained by trade in intermediate inputs (Johnson and Noguera, 2012). Offshoring processes and global chains of production are responsible for such a growth in inputs trade. Firms in developed countries divide their production in several stages and locate them in emerging countries where they benefit from a comparative advantage (wages, flexibility, environmental regulation, taxes, etc).

Environmentally the effect is such that 30% of emissions linked to production in the world economy in 2004 are internationally traded (Davis *et al.*, 2011). This impact differs between developed and developing countries (Wiedmann *et al.*, 2007; Peters and Herwitch, 2008a; Chen and Chen, 2011; Davis *et al.*, 2011). The methodology of emissions balance shows a deficit for developed countries, as they import directly or indirectly CO_2 intensive goods in exchange for exporting environmentally-friendly goods, and they suffer trade deficits. Currently, it is possible for developed countries to overcome Kyoto Agreement by not producing domestically polluting goods, but buying them from foreign countries (Muradian *et al.*, 2002). On the other hand, Levinson (2009) found for US international trade that the increase of net imports of polluting goods accounts only for a small proportion of the pollution reductions in emissions by US manufacturers. Emerging countries, on the contrary, present a surplus in the emissions balance as they, on the one hand, export goods more CO2 intensive than the ones they import, and on the other, keep trade surplus in final and, above all, intermediate inputs commerce. Nevertheless, we cannot use this balance to quantify whether the impact from trade on the environment allows us to reduce emissions for the world as a whole. The reason for this is that the trade balance is different from zero while the sum of the emissions balance for all countries in the world is always zero.

From the point of view of the global economy, it is most efficient to produce each good where it pollutes the least, where there is a comparative environmental advantage (Peters and Herwitch, 2008a), both direct and indirectly. The Pollution haven hypothesis (PHH) implies that a reduction in trade barriers increases trade and subsequently emissions (Coopeland and Taylor, 2004). This hypothesis is analysed using the balance of avoided emissions (BAE), that is calculated as the difference between emissions linked to exports and emissions avoided by imports in international trade. Mongelli *et al.* (2006) shows, using a single region input-output model for Italy, the presence of carbon leakage, but they do not found support for the pollution haven hypothesis. Dietzenbacher and Mukhopadhyay (2007) and Zhang (2012) apply a single region input-output model to the analysis of pollution embodied in exports, in terms of emissions, and that avoided by imports, for India in the first paper and China in the second. Both papers find a negative balance in net exported embodied carbon, for India between 1991/992 and 1996/1997, and for China between 2000 and 2005. According to the authors this result shows that the emissions pattern implies that trade helped in both countries to lower its total carbon emissions. However, between 2005 and 2007 emissions embodied in Chinese exports are higher than those avoided by imports, as the country becomes a net exporter. In terms of D&H this conforms to the PHH, as emissions grow via international trade (even though, according to these authors, we will also need to study the result of the emissions from this trade in the rest of the world).

Although trade means a country can avoid emissions, international trade might generate an increase in emissions for the world economy as a whole. Firstly, because we must realise that this trade might increase or decrease emissions in the rest of the world (Dietzenbacher and Mukhopadhyay, 2007)[1]. Secondly, because a single region input-output model does not take into account the successive rounds of international production. These problems are solved in Chen and Chen (2011) as they use a multi-region input-output (MRIO) model and calculate the difference between the emissions avoided by imports (EAI) and emissions embodied in imports (EEI)[2] between G7, BRIC and the rest of the world (ROW) to evaluate this effect. They find that world trade increased emissions by 0.13 billion tons in 2004 over a total of 5.77 billion tons of EEI. Thirdly, it does not include the increase in emissions linked to the international freight transport of products that move around the globe as parts and components until they are finally assembled in final goods (Cadarso et al, 2010, Cristea *et al.* 2011).

In this paper we develop a two-region input-output model and a multi-region model to analyse whether the different rounds or stages of production and/or trade in final goods are responsible for the existence (or not) of the PHH. Our proposal allows us to decompose the BAE, by countries and by type of traded goods, into three different balances: a) balance of avoided emissions in final goods, b) BAE in intermediate inputs required for the last stage of production, and c) BAE of intermediate inputs required for all other stages of production, from the first to the penultimate. This means we can isolate the role of the different countries involved in global chains of production and, from that point, we can analyse their environmental impact. Finally we apply this

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[1] Dietzenbacher & Mukhopadhyay (2007) use a similar analysis by calculating the balance from a million euros of exports and avoided imports, keeping constant their relative industry distribution. A positive balance would imply that international trade generates a growth in emissions. Nevertheless, this measure does not allow us to isolate the importance of changes in industry distribution on trade balance.

[2] This means that Chen and Chen (2011) take into account simultaneously the technology of production in all considered countries, while in the papers by Dietzenbacher & Mukhopadhyay (2007) and Zhang (2012) only technology for the country of analysis is included.

methodology to a bi-region model of trade between Spain and China in the period 2000-2010.

The paper is divided in four sections. Section 2 develops the methodology on the impact of international trade on environment, and section 3 shows and comments the results from applying this methodology. Finally, section 4 is devoted to discuss the main conclusions found in the paper.

2. METHODOLOGY

2.1 Trade balance in uni-regional and bi-regional models.

The expression for trade balance by commodities for country 1 in an **uni-regional** input-output model is:

$$TB_1 = X_1 - M_1 = X_1 - \left[A_1^m \left[1 - A_1^d\right]^{-1} y_1^d + y_1^m\right] \quad (1)$$

where X_1 is country 1 exports vector, A_1^d is the domestic technical coefficient matrix, , A_1^m the imported coefficient matrix, y_1^d the final domestic demand vector and y_1^m the imported final demand vector. A positive sign in a given commodity in the resulting vector points to a surplus in the trade balance for that commodity, while a negative sign points to a deficit. The aggregation of the vector elements is the trade balance for country 1.
A bi-regional model, works with information of country 1 and the rest of the world or country 2 ($X_1 = M_2$). With only two countries country 1 exports are equal to country 2 imports, so the expression for trade balance for country 1would be the following (just the opposite for country 2):

$$TB_1 = X_1 - M_1 = \left[A_2^m \left[1 - A_2^d\right]^{-1} \hat{y}_2^d + \hat{y}_2^m\right] - \left[A_1^m \left[1 - A_1^d\right]^{-1} \hat{y}_1^d + \hat{y}_1^m\right] \quad (2)$$

where elements are similar to those in expression 1 and suffix 2 indicates country 2. The use of ^ indicates diagonalised vectors, allowing to work either by rows or by columns.

Expression 2 is modified by considering separately two demand (y_1^d) components, the one that remain within frontiers, (y_1^r), that contains private consumption, investment and public expenditure, and exports (y_1^x). We also define the imports multipliers for country 1 and 2, $L_i^m = A_i^m \left[1 - A_i^d\right]^{-1}$. We then obtain three separate trade balances:

$$TB_1 = \underbrace{\left[\hat{y}_2^m - \hat{y}_1^m\right]}_{3.1} + \underbrace{\{[L_2^m \hat{y}_2^r] - [L_1^m \hat{y}_1^r]\}}_{3.2} + \underbrace{\{[L_2^m \hat{y}_2^x] - [L_1^m \hat{y}_1^x]\}}_{3.3} \quad (3)$$

Expression 3.1 quantifies trade balance for final goods, and it measures, for each sector, the value of commodities sold to country 2 final consumers by country 1 (that might be private or public consumption or investment goods) minus the value of commodities from country 2 by country 1 final consumers. Results are symmetric by rows or columns: millions of Euros per internationally traded commodity.

Expression 3.2 quantifies trade of imported intermediate goods that will be used in the production process of domestically demanded goods. According to global value changes analysis, these goods belong to the last commodities international trade round. Expression 3.2 provides different lectures by rows and by columns. By rows it calculates the difference between commodity *i* imports needed by country 1 (country 2 exports) and those needed by country 2 (country 1 exports) to produce any commodity consumed domestically. A positive sign points to country 1 selling more intermediate commodity *i*, for country 2 domestically consumed production, than the purchased one for domestic production. The rows, or products, result shows total exports and imports of commodity *i* between both countries. By columns, it shows the difference between exports and imports of all the goods required to produce a given commodity *j* in country 2 and country 1, but only for that part of *j* that is sold domestically. Therefore, by columns we obtain international dependence of a domestic sector: a strong negative the result shows a high dependence of domestic final demand of a foreign intermediate good. It is a vertically integrated sectors analysis that does not measure direct trade for given commodities.

Expression 3.3 shows trade balance for inputs that will be used in future international rounds of production, apart from the last one collected by 3.2. Each element in this balance accounts for the value of global value chains of production. Previous specialised literature defines this element as vertical specialization (Hummels *et al* 2001), so that signs in 3.3 provide information on differences in countries vertical specialization (Cadarso *et al.* 2007). The sign of this element shows the difference between country 1 exports that will be later imported as part of final goods, and country 1 imports that will be exported embodied in final goods. A positive sign shows that country 1 is specialised in the production of goods that will have their last stage of production in other countries and will be re-imported as final goods, more than in importing intermediate goods that will be used to produce final goods.

Analysing by components, the first one in 3.3 shows intermediate exports from country 1 to country 2 required to produce final or intermediate goods to country 1, and the opposite for the second component. We could think in GPS exports of country 1 that country 2 fits in cars that will be sold to country 1. In a three goods example the relationships are more complex, country 2 buys country 1 chips that are used to produce GPS that will be sold to country 1 to be fitted in cars finally sold to country 2.

In our example, working in rows or commodities, country 1 exports are the result of the aggregation of the value of two goods (chips and cars electronic panel components) and imports consider the value of one product, GPS. Therefore, for the balance as a whole, exports are compensated in part by imports, however, analysis by product will show surplus in chips and cars electronic panels for country 1 and deficit for GPS (the opposite for country 2). Sectoral unbalance could be unappreciable when working at an aggregate level.

When working by columns, results show imports of any good required to produce good *j* in country 1 that will be exported in its final stage to country 2 (the opposite for country 2). As it happens in expression 3.2, its value does not coincide with the commodities trade balance for both countries.

2.2 Domestic emissions balance in uni-regional and bi-regional models.

When building a bi-regional model balance of domestic emissions (BDE), only those emissions associated to the generation of value added that is responsibility of each of the two countries are considered, but leaving aside all emissions generated in any other stage of production or trade rounds. BDE is useful to isolate the environmental impact of trade between a country and the rest of the world (SRIO) or between two countries or geographical areas (bi-regional). This model is adequate to identify the impact of delocalisation of a given stage of production of a commodity for the two implied countries, removing the effects in any other country.

The calculation of a BDE for a uni-regional model, (UBDE), is similar to the calculation of a trade balance but considering the domestic emission multipliers for the implied country:

$$UBDE_1 = X_1 - M_1 = \varepsilon_1 X_1 - \varepsilon_2 [A_1^m [1 - A_1^d]^{-1} y_1^d + y_1^m] \quad (4)$$

where ε_1 is the domestic emissions multiplier for country 1, calculated by multiplying the emissions direct coefficient for country 1 ($e_1 = E_1 / q_1$), or emissions per produced unit, times the Leontief inverse ($\varepsilon_1 = e_1 \left[1 - A_1^d\right]^{-1}$). The emissions multiplier considers direct and indirect emissions associated to the production of a unit of final product. In a similar fashion, country 2 domestic emissions multiplier is calculated as $\varepsilon_2 = e_2 \left[1 - A_2^d\right]^{-1}$. It is also possible to define the total emissions multiplier, that considers all emissions, domestic and imported, required for production within a country ($\varepsilon_2^t = e_2 \left[1 - A_2^t\right]^{-1}$ for country 2), what involve to work with Leontief inverse in total terms (domestic plus imported technical coefficients). It is important to recall that the use of the total coefficients matrix in uni-regional and bi-regional models imposes the hypothesis of a production and emissions technology similar to the domestic one for all the trading countries (domestic technology assumption, DTA).

The expression for the domestic emissions balance in a bi-regional model is similar to that in 3 multiplied by the country's emissions multiplier:

$$BBDE_1 = E_1^X - E_1^M = \underbrace{\varepsilon_1[L_2^m \hat{y}_2^d + \hat{y}_2^m]}_{5.1} - \underbrace{\varepsilon_2[L_1^m \hat{y}_1^d + \hat{y}_1^m]}_{5.2} \quad (5)$$

Expression (5) provides an emission balance similar to the definition of emissions embodied in bilateral trade (EEBT) in Peters (2008). Both use bilateral trade and domestic emissions for each country production and sales, excluding the use of DTA. Also, neither takes into account international feedback emissions (Su and Ang, 2011). The main difference between them is that EEBT does not split the bilateral trade flow into its components, intermediate and final consumption, whereas BBED does. As a result, they imply two different emission allocation criteria by sector. EEBT allocates emissions to the origin sector, the producing one. BBDE shows the same results and allocation criteria when considered by rows. By columns, BBDE allocate emissions to the user sector[3] and shows different results.

Within the domestic emissions balance it is possible to consider three different elements, as it was the case for the trade balance:

$$BBDE_1 = E_1^X - E_1^M = \underbrace{\varepsilon_1 \hat{y}_2^m - \varepsilon_2 \hat{y}_1^m}_{6.1} + \underbrace{\varepsilon_1[L_2^m \hat{y}_2^r] - \varepsilon_2[L_1^m \hat{y}_1^r]}_{6.2} + \underbrace{\varepsilon_1[L_2^m \hat{y}_2^x] - \varepsilon_2[L_1^m \hat{y}_1^x]}_{6.3} \quad (6)$$

So it is possible to distinguish three sub-balances: 6.1 accounts for final goods trade emissions; 6.2 for inputs trade emissions whenever inputs are in the last international production round, since they will be incorporated to final goods sold domestically; and, finally, 6.3 for emissions associated to any previous international trade rounds required to produce traded intermediate inputs that will keep on adding value in the global value chain.

The bi-regional model can be used to isolate trade of country 1 with another country, country 2, or the rest of the world. For the two countries case, the impact on the rest of the world should also be considered. As an example, the amount of emissions in goods produced by country 1 that will be used as intermediate inputs to produce final goods that will be exported elsewhere must be quantified.

The distinction can be done by decomposing each country 1 y exported final demand as: $\hat{y}_2^x = \hat{y}_{21}^x + \hat{y}_{2RM}^x$, where the first element accounts for country's 2 exports to country and the second country's 2 exports to the rest of the world (the expression for country 1 is $\hat{y}_1^x = \hat{y}_{12}^x + \hat{y}_{1RM}^x$). As a result, expression in 6.3 can be decomposed in two expressions, 6.3.i accounts for emissions associated to consecutive rounds of production between country 1 and 2, while 6.3.ii. accounts for international rounds of commodities exchanged between countries 1 and 2 that end up as final goods to other

[3] As in a MRIO model.

countries (either as final or intermediate goods). So expression in 6 is transformed as follows:

$$\underbrace{\varepsilon_1[L_2^m \hat{y}_2^x] - \varepsilon_2[L_1^m \hat{y}_1^x]}_{6.3} = \underbrace{\varepsilon_1[L_2^m \hat{y}_{21}^x] - \varepsilon_2[L_1^m \hat{y}_{12}^x]}_{6.3.i} + \underbrace{\varepsilon_1[L_2^m \hat{y}_{2RM}^x] - \varepsilon_2[L_1^m \hat{y}_{1RM}^x]}_{6.3.ii} \quad (6.b)$$

A temporal analysis of the previous balances provides information on the importance of the different types of commodity trade on environment. Our main interest is to quantify the effect of global value changes on total emissions. It is also of great interest to develop both commodities/rows and sectors/ columns analysis, as commented for trade balance in the previous section. Finally, the minimisation of environmental effects can be studied by considering the possibility of modifying emissions intensity for specific countries. The possibility of technologies transference can be modelled and its consequences measured by the consideration of exchanging technical and polluting coefficient among countries.

When only direct emissions are considered the expression becomes:

$$dBBDE_1 = E_1^X - E_1^M = \underbrace{e_1\hat{y}_2^m - e_2\hat{y}_1^m}_{6..1} + \underbrace{e_1\hat{y}_2^r - e_2\hat{y}_1^r}_{6..2} + \underbrace{e_1\hat{y}_2^x - e_2\hat{y}_1^x}_{6..3} \quad (6.c)$$

In this case, 6.1, 6.2 and 6.3 show balances of avoided direct emissions associated to final goods trade, last round intermediate goods and inputs in other production rounds. Differences between BBDE and dBBDE for each component measure the value of indirect emissions associated to international trade by commodities.

2.3 Trade and domestic emissions balances in a multiregional input-output model (MRIO)

The MRIO model widens the basic input-output model to include several regions or countries with different technology and trade between them. For the sake of simplicity, we consider two countries (r=2), denoted by superscript 1 and 2 (country 2 is the rest of the world) and n sectors (in subscripts). In this way, A^{ii} is the matrix of domestic production coefficients and A^{ij} is the matrix of imported coefficients from country i to country j, y^{ii} is the domestic final consumptions and y^{ij} is country i's final demand exports to country j. F^{ij} includes all the emissions from country i required to satisfy country j's demand. Using the partitioned form to represent the model:

$$\begin{bmatrix} F^{11} & F^{12} \\ F^{21} & F^{22} \end{bmatrix} = \begin{bmatrix} P^{11} & P^{12} \\ P^{21} & P^{22} \end{bmatrix} \begin{bmatrix} y^{11} & 0 \\ 0 & y^{22} \end{bmatrix} + \begin{bmatrix} P^{11} & P^{12} \\ P^{21} & P^{22} \end{bmatrix} \begin{bmatrix} 0 & y^{12} \\ y^{21} & 0 \end{bmatrix}$$
$$= \begin{bmatrix} P^{11}y^{11} & P^{12}y^{22} \\ P^{21}y^{11} & P^{22}y^{22} \end{bmatrix} + \begin{bmatrix} P^{12}y^{21} & P^{11}y^{12} \\ P^{22}y^{21} & P^{21}y^{12} \end{bmatrix} \quad (7)$$

The first matrix shows emissions embodied in domestic final demand supplied by their own. In this matrix we have, by rows, emissions in one country (first row country 1) generated in the production of self-covered domestic final demand of all countries. By columns, we have, emissions all over the world generated by the supplying of own final demand in one country (first column own final demand of country 1). The second matrix in equation (7) shows emissions embodied in exports: by rows, emissions in a country (first row country 1) embodied in exports of both countries and, by columns, emissions all over the world embodied in a country exports (first column country 2 exports).

In a similar fashion as in the two-region model, we can define the balance of domestic emissions in a multi-region model (BDEM) for country 1 as the difference between domestic emissions linked to exports from country 1 (8.1) and emissions generated in the rest of countries from where all imports by country 1 come (8.2). The expression is as follows:

$$\begin{aligned} BDEM^1 &= EEXN^1 - EMMN^1 \\ &= \underbrace{\left(P^{11}\hat{y}^{12} + P^{12}\hat{y}^{22} + P^{12}\hat{y}^{21}\right)}_{8.1} - \underbrace{\left(P^{21}\hat{y}^{12} + P^{21}\hat{y}^{11} + P^{22}\hat{y}^{21}\right)}_{8.2} \\ &= \underbrace{\left(P^{11}\hat{y}^{12} - P^{22}\hat{y}^{21}\right)}_{8.3} + \underbrace{\left(P^{12}\hat{y}^{22} - P^{21}\hat{y}^{11}\right)}_{8.4} + \underbrace{\left(P^{12}\hat{y}^{21} - P^{21}\hat{y}^{12}\right)}_{8.5} \end{aligned} \tag{8}$$

The term 8.3 shows the balance of emissions linked to trade in final goods (it is the same as 6.1). The term 8.4 shows the balance of emissions linked to trade in intermediate inputs that belong to the last stage of international production, as when they enter the country these inputs become embodied in the production of final goods that are sold domestically (it is the same as 6.2). Expression 8.5 is the balance of emissions linked to any other round of international production required to produce final goods. This is the case as they are emissions of country 1 that enter country 2 and are used to produce in this country and later on exported (the opposite will be true for imports) (it is the same as 6.3). This balance captures emissions embodied in the consecutive rounds and steps of the production of a commodity caused by the fragmentation of production and the creation of global product chains.

This balance of domestic emissions has some advantages versus the balances previously used in the literature. In comparison to the definitions of the emission trade balance (ETB) or the responsibility emission balance (REB) either used by Munksgaard and Pedersen (2001), Muradian *et al.* (2001), Peters and Hertwich (2008a), Ahmad and Wyckoff (2003), Sánchez-Chóliz and Duarte (2004) and Serrano and Dietzenbacher (2010), there is no cancelation of emissions linked to the imports that are later exported in the BEDB and BDEM. This is a relevant component of trade and emissions that must not be neglected in the measurement of environmental impact of trade. It shows the international stages of production and would be considered as the emission equivalent to the concept of vertical specialization defined by Hummels *et al.* (2001). As opposed to the sales balance (SEB) of Kanemoto *et al.* (2012), where international stages of production do not cancel out, BEDB and BDEM do take into account emissions linked to intermediate inputs that are not included in SEB. On the other hand, in Kanemoto emissions balance it is required that the aggregation of all countries balance has to cancel out emissions, as it happens to BEDB and BDEM. However, this property prevents the use of the balance to analyse whether the impact of trade on environment leads to a reduction in emissions.

2.4 Pollution haven hypothesis in a context the global value chain

Dietzenbacher & Mukhopadhyay (2007), Zhang (2011) and Chen & Chen (2011)[4] use the difference between emissions linked to exports (EEX) and emissions avoided by imports (EAM) to evaluate whether international trade increases or decreases emissions at a global level. If the first option can be proven, then we will be in the case called by D&H pollution haven hypothesis. Starting from the work of those authors and the previous decomposition of the balance of domestic emissions, we propose a methodology that allows us to analyse whether the specialisation of countries in different stages of production and/or trade in final goods generate an increase or a decrease of emissions due to international trade.

The expression that calculates the impact of trade on the growth of emissions in a multi-region model through the balance of avoided emissions (BAE) is as follows:

$$BAE = \mathrm{EEX} - \mathrm{EAM} = \sum_{j=1}^{n} \varepsilon_j X_j - \sum_{j=i}^{n} \varepsilon_j M_i \tag{9}$$

The difference of this balance of emissions can only be explained by the different pollution intensity of the trading countries, as exports from one country are imports for the rest ($\sum X_1 = \sum M_2$). This implies that a positive balance of BAE will conform to the pollution haven hypothesis, as the growth in emissions would be explained by trade moving production to more polluting countries. The reason is that, in this case, emissions generated by trade are higher than if those goods had been produced within the country using domestic technology and without international trade. A negative balance for the BAE implies that emissions are decreasing due to trade between countries, as goods are produced where they generate the least pollution. Nevertheless, this formulation by D&H underestimates the impact from trade on the environment because: a) it does include international freight transport, b) it does not

[4] Chen and Chen (2011) define it as emissions linked to imports and emissions avoided by those imports, even thought the result is not the same.

consider the possibility of global chains of production being different in both countries, meaning that the country where imports originate might also move part of its production to other country. In order to solve this second problem we must either build a multi-regional model including the whole world economy (Chen and Chen, 2011) or a two-region model that considers all stages under the DTA assumption, changing the direct (ε_1) by the total emissions multipliers (ε_1^t). However emissions from international freight transport must be explicitly calculated (Cadarso *et al.*, 2010).

Our contribution is to decompose the balance of the BAE to analyse the importance of trade in different types of goods, intermediate or final, for the environment and therefore, global chains of production. In a two-region (countries) model, the expression that reflects emissions from exports by both countries is (EEX): $\varepsilon_1 X_1 + \varepsilon_2 X_2$. Emissions avoided by those imports are given by (EEM): $\varepsilon_1 M_1 + \varepsilon_2 M_2$. From that we propose to decompose the balance between them as:

$$
\begin{aligned}
\sum \mathrm{BAE} &= (\varepsilon_1 \mathrm{X}_1 + \varepsilon_2 \mathrm{X}_2) - (\varepsilon_1 \mathrm{M}_1 + \varepsilon_2 \mathrm{M}_2) = \varepsilon_1(\mathrm{M}_2 - \mathrm{M}_1) + \varepsilon_2(\mathrm{M}_1 - \mathrm{M}_2) \\
&= \left[\underbrace{\varepsilon_1[L_2^m \hat{y}_2^d + \hat{y}_2^m]} + \underbrace{\varepsilon_2[L_1^m \hat{y}_1^d + \hat{y}_1^m]}\right] \\
&\quad - \left[\underbrace{\varepsilon_2[L_2^m \hat{y}_2^d + \hat{y}_2^m]} - \underbrace{\varepsilon_1[L_1^m \hat{y}_1^d + \hat{y}_1^m]}\right] \\
&= \left[\underbrace{\varepsilon_1 \hat{y}_2^m - \varepsilon_1 \hat{y}_1^m}_{10.1} + \underbrace{\varepsilon_2 \hat{y}_1^m - \varepsilon_2 \hat{y}_2^m}_{10.1}\right] \\
&\quad + \left[\underbrace{\underbrace{\varepsilon_1[L_2^m \hat{y}_2^r] - \varepsilon_1[L_1^m \hat{y}_1^r]} + \underbrace{\varepsilon_2[L_1^m \hat{y}_1^r] - \varepsilon_2[L_2^m \hat{y}_2^r]}}_{10.2}\right] \\
&\quad + \left[\underbrace{\varepsilon_1[L_2^m \hat{y}_2^x] - \varepsilon_1[L_1^m \hat{y}_1^x] + \varepsilon_2[L_1^m \hat{y}_2^x] - \varepsilon_2[L_2^m \hat{y}_1^x]}_{10.3}\right]
\end{aligned} \tag{10}
$$

Expressions 10.1 show the balance of emissions avoided by trade in final goods between both countries. The terms in 10.2 show the balance of emissions avoided by trade in inputs that belong to the last stage of international production, as when they enter the country these inputs become embodied in the production of final goods that are sold domestically (it is the same as 6.2). Expression 10.3 is the balance of emissions linked to the rest of rounds of international production required to produce goods to attend final demand. This is the case as they are emissions of country 1 that enter country 2 and are used to produce in this country and later on exported (the opposite will be true for imports) (it is the same as 6.3).

If we were to consider only direct emissions linked to international trade, the formula to calculate the balance of direct avoided emissions (BAEd) will be as follows:

$$\sum BAEd = (\mathrm{e_1X_1 + e_2X_2}) - (\mathrm{eM_1 + e_2M_2}) =$$

$$= \left[\underbrace{e_1\hat{y}_2^m - \varepsilon_1\hat{y}_1^m}_{10..1} + \underbrace{e_2\hat{y}_1^m - e_2\hat{y}_2^m}_{10..1}\right] + \left[\underbrace{e_1\hat{y}_2^r - e_1\hat{y}_1^r + e_2\hat{y}_1^r - e_2\hat{y}_2^r}_{10...2}\right] + \left[\underbrace{e_1\hat{y}_2^r - e_1\hat{y}_1^r + e_2\hat{y}_2^r - e_2\hat{y}_1^x}_{10..3}\right]$$

(10.b)

Expressions 10..1, 10..2 and 10..3 show the balance of direct avoided emissions linked to trade in final goods, intermediate inputs for the final stage and inputs for the rest of stages of production. The difference between each component of BAE and BAEd would give us the indirect avoided emissions linked to international trade for each good.

This same analysis can be implemented in a multi-regional model, with the objective of identifying the importance in terms of environmental impact of different countries according to their role in the global chains of production and of different types of traded goods, intermediate and final.

$$\sum BAE = \mathrm{EEX} - \mathrm{EAM} = \sum_{\mathrm{j=1}}^{2} \mathrm{\varepsilon_j X_j} - \sum_{\mathrm{j=i}}^{2} \mathrm{\varepsilon_j M_j}$$

$$= \left[\underbrace{(P^{11}\hat{y}^{12} + P^{12}\hat{y}^{22} + P^{12}\hat{y}^{21})}_{11.} + \underbrace{(P^{21}\hat{y}^{12} + P^{21}\hat{y}^{11} + P^{22}\hat{y}^{21})}_{11.}\right]$$

$$- \left[\underbrace{(P^{22}\hat{y}^{21} + P^{21}\hat{y}^{11} + P^{21}\hat{y}^{21})}_{11.} + \underbrace{(P^{12}\hat{y}^{12} + P^{21}\hat{y}^{22} + P^{22}\hat{y}^{12})}_{11.}\right] =$$

$$= \left[\underbrace{(P^{11}\hat{y}^{12} - P^{11}\hat{y}^{21})}_{11.1} + \underbrace{(P^{22}\hat{y}^{21} - P^{22}\hat{y}^{12})}\right]$$

$$+ \left[\underbrace{\underbrace{(P^{12}\hat{y}^{22} - P^{12}\hat{y}^{11})} + (P^{21}\hat{y}^{11} - P^{21}\hat{y}^{22})}_{11.2}\right]$$

$$+ \left[\underbrace{(P^{21}\hat{y}^{21} - P^{12}\hat{y}^{12})}_{11.3} + \underbrace{(P^{21}\hat{y}^{12} - P^{21}\hat{y}^{21})}_{11.}\right]$$

(11)

The meaning of expressions 11.1, 11.2 and 11.3 are similar to expressions 10.1, 10.2 and 10.3. The difference is that the first ones come from the MRIO framework, so these balances capture emissions embodied in the consecutive rounds and steps of the production of a commodity caused by the fragmentation of production and the creation of global product chains.

3. Empirical application for Spanish-Chinese trade

3.1. Data sources

Data sources for the paper are the following: OECD 2005 input-output tables, in millions of Euros, are used to calculate emissions related to exports from Spain to China; Atmospheric Emissions Satellite Accounts, published by INE, provide information on CO_2 emissions in thousands of tons for the same year. Data have been aggregated to 28 sectors. Since Spanish input-output tables do not provide information about imports and exports by destination country, we have completed them by using Dirección General de Aduanas information (Customs Department) to obtain the Spanish-Chinese trade for 2005 and 2010. Following this procedure we obtain emissions related to both countries for this period, to obtain these figures we suppose that, for the whole period, production and polluting technology remain constant as in 2005.

The calculation of imports emissions has also been done working with OECD Chinese input-output tables, which provide data expressed in 10.000 Yuanes (Renminbi), so that the European Central Bank exchange rate was required to obtain results in Euros. Results were aggregated to 23 sectors. To calculate the CO_2 emissions related to energy goods consumption IPCC information on Carbon and CO_2 emissions was used, as well as data on Chinese energy consumption for 2005 by productive sectors, provided by the China Statistical Yearbook annually presented by the National Bureau of Statistics of China.

Chinese emission factors have been obtained based on IPCC data[5] on emissions derived from energy goods combustion. The method used, explained in detail in Annexe 2, is to multiply by the caloric conversion in carbon factor for each considered energy source. Following this procedure we obtain carbon tons by product took to combustion. When this amount is multiplied by the oxidation factor, the emissions factor (tCO_2/kt) that we were looking for is obtained. CO_2 tons (tCO_2 from now onwards) generated by the Chinese economy in 2005 will be calculated multiplying our emissions factor by the available Chinese energy consumption matrix for 2005 (see annexe 2).

Data on imports by sector for Spain and China have been obtained from the Customs Department in millions Euros. For each sector, two types have been considered, final goods and intermediate goods, by using the proportion of those for total industry imports. For international trade data the effect of prices has been deleted, taking into

[5] As noted in Zhang (2012), there exist different data sources to calculate emissions factors. We can find works like those of Peters *et al.* (2007), Zhang (2012) or Lin and Sun (2010) that, just like ours, combine data on energy consumption from China Statistical Yearbook with IPCC data on emission coefficients. Other papers like Liu *et al.* (2010) use data provided by the Chinese Energy Statistical Yearbook and the China Energy Data Book.

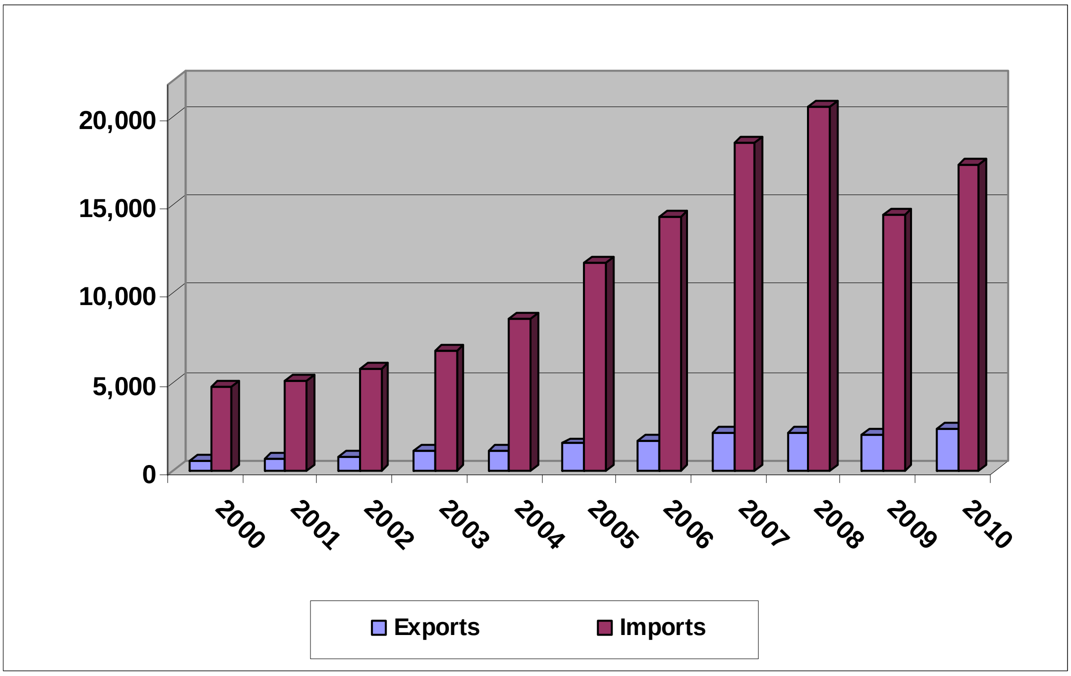
account as reference year 2005. The GDP deflator given by the Bank of Spain has been used for Spanish data, while for Chinese data the GDP provided by the World Bank was used.

3.2 Spanish-Chinese trade: final and intermediate inputs

The commercial relationships of Spain with the rest of the World have grown notably in the last decades. Only the 2008 economic crisis curbed temporarily this trend leading to a reduction in economic activity, in demand and a lack in finance. The original increase in international trade was explained by the European integration process, which was reinforced by an increase in worldwide trade relationships due to globalization and the entrance of China and India in the international scene.

The commercial balance between Spain and China is markedly negative for Spain (Figure 2). While Spanish exports to China have kept at low levels, Chinese exports to Spain have been constantly increasing. Commercial deficit grows from 4.159 millions of Euros in 2000 to more than 14.880 in 2010. We must consider whether Spanish trade with China is based on final or intermediate goods and services, as considered in expression (6). The distribution is shown in Table 1. Data show that the distribution is very similar for both final and intermediate demand, slightly higher for final demand. Financial crisis affects more intermediate demand, with a steeper reduction at the beginning of the crisis, and a faster increase in 2010.

Figure 2: Bilateral trade from Spain to China 2000 - 2010 (millions of Euros).



Source: Own elaboration from Industry, Tourism and Trade Ministry (DataComex).

Table 1: Spanish imports from China: Distribution between final and intermediate demand (millons of Euros).

	Intermediate Demand		Final Demand		Total
	Value	%	Value	%	
2005	5.478,07	46,9	6.214,12	53,1	11.692,19
2006	7.092,70	49,5	7.246,79	50,5	14.339,49
2007	8.673,45	52,7	7.779,78	47,3	16.453,24
2008	9.436,09	50,7	9.168,00	49,3	18.604,08
2009	6.490,36	46,5	7.452,83	53,5	13.943,19
2010	7.836,04	47,5	8.666,40	52,5	16.502,44

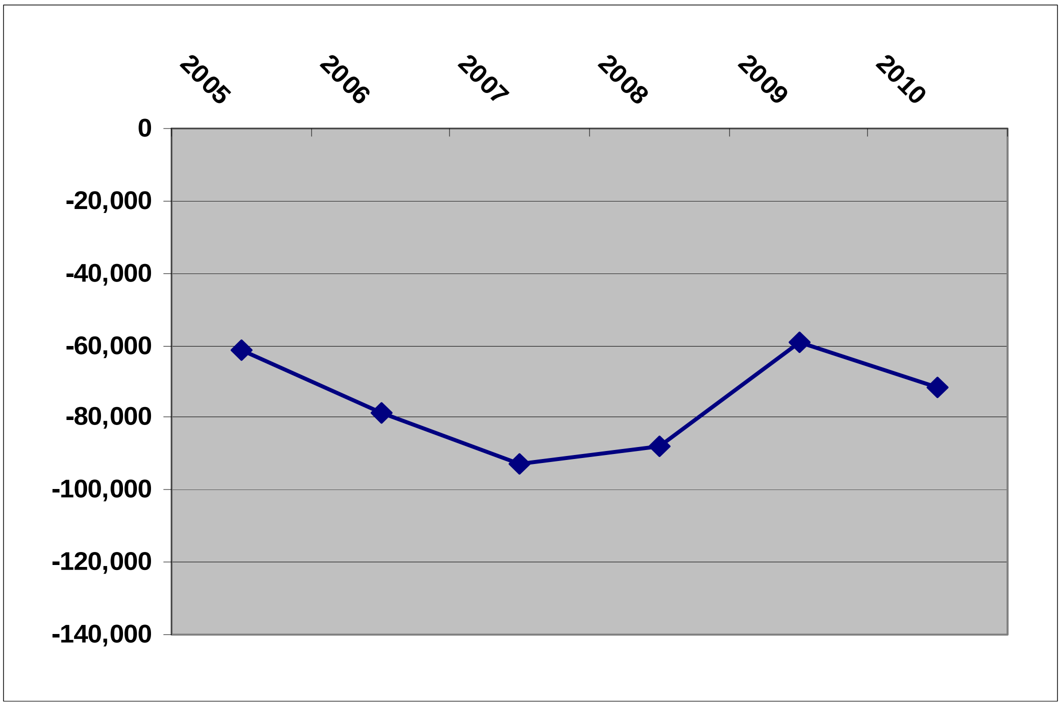
Source: Own elaboration from 2005 imported input-output and customs department (Dirección General de Aduanas in Spanish).

3.3. CO_2 emissions and Spain-China trade

The methodology used in this paper allows us to analyse the economic structure from the inter-industrial relationships, so that it is possible to calculate data on emissions embodied in bilateral trade between Spain and China by sector. The obtained emissions are inclusive of direct emissions generated in the productive process and also indirect ones, so that the dragging effect of bilateral trade in each sector in terms of environmental impact and emissions responsibility are considered. Global figures show that direct emissions balance is -7.047,7 millions of tCO_2, however, when all dragging effects are included, emissions deficit is much higher, with direct emissions being only 9,8% of total deficit in 2010.

Total emissions balance (see annexe 1, tables 2 and 3) between Spain and China shows an acute negative sign for Spain between 2005 and 2010 (Figure 3). There is also a growing deficit in emissions balance that improves markedly in 2009, mainly because of the reduction in international trade flows during the crisis. In 2010 the deficit got slowly back to its previous path, reaching the amount of -71,629.94 thousands of tCO_2. The deficit extend becomes obvious when analysing 2005 data, when out of the 61,242.87 thousands of tCO_2 deficit, total emissions generated in Spanish production was 287,927 tons. Summarizing, Spanish imports from China only get to 1.44% of Spanish GDP, however they explain 21.2% of Spanish emissions. If environmental criteria are not considered when analysing international trade, neither consumers nor producers respond as responsible for emissions, so a substantial portion of environmentally harmful consequences are obviated.

Figure 3: Spain-China Emissions balance, thousands of CO_2 tons.



Source: Own elaboration from 2005 imported input-output and customs department (Dirección General de Aduanas in Spanish).

This acute negative CO_2 emissions balance is explained by two main reasons: first is the important commercial deficit between Spain and China, where Spanish exports to China only get to 12.8% of imports in 2005, a percentage that keeps at present; second is the different intensity of emissions incorporated in production of goods and services for each country. Li and Hewitt (2011) show the huge increase in Chinese energetic consumption explained by the massive economic growth model based in exports and his energetically dependent growth.

Table 2 shows a much higher China emission's factor than the Spanish one in 2005. Among the most polluting sectors in both countries we find Energy extraction, Production and distribution of electric energy, gas and water and Rubber, plastic materials and non-mineral metals. All of them are more polluting in China than in Spain, with a particularly marked difference in Production and distribution of electric energy, gas and water with an emission factor of 2.41 tCO_2 thousands per million of Euros in Spain compared to 12.24 in China. This huge difference is explained by the Chinese use of coal (mainly anthracite) in China as the main energy source, producing almost 80% of the energy used by industry, trade and households (AIE, 2009). However, Chinese government intends to increase the weight of alternative cleaner technologies, including Natural gas (only 5% of total energy at the moment), and to close some of the smaller and less efficient thermal centrals down (according to U.S. EIA, 2009).

Table 2: Emissions coefficients for Spain and China for 2005, tCO_2 thousand per million of € produced.

	Spain	China
Agriculture, stockbreeding, hunting, silviculture and fishing	0.25	0.32
Energy products extraction	1.07	2.67
Extraction of other minerals excepting energy products	0.10	0.42
Foods, beverages and tobacco	0.07	0.26
Textile, clothing, leather and footwear.	0.10	0.21
Wood and Cork	0.07	0.16
Paper, publishing and graphic arts	0.13	0.65
Mineral oil refining, and nuclear fuels	0.65	9.27
Chemicals	0.22	1.10
Rubber & plastics	0.00	3.15
Non-metallic mineral products	1.61	
Metallurgy and fabricated metal products	0.22	
Iron and steel		3.07
Metallic products fabrication except machinery and equipment		0.11
Machinery and mechanical equipment	0.03	0.14
Electric, electronic and optical machinery and equipment	0.01	
Electric machinery and appliances		0.03
Telecommunication equipment, Computers and other Electronic		0.04
Office machinery, accountancy and computing machinery		0.03
Transport material	0.03	0.50
Miscellaneous manufacturing	0.03	0.07
Electricity, gas and water supply	2.41	12.24
Construction	0.02	0.09
Motor vehicles and reparation, household articles	0.04	0.17 (4)
Hotels & catering	0.00	
Transport, storage and communications	0.27	1.16
Financial intermediation	0.01	0.44 (5)
Real estate activities and business services	0.00	
Public administration, defence and compulsory social security	0.01	
Education	0.00	
Health and social work	0.02	
Other community, social & personal services	0.05	
Private households with employed persons	0	

Note: All applicable to Chinese data.

(1) Other non-metallic mineral products and Non-mineral products were aggregated to Rubber and plastics.
(2) Metallurgy and fabricated metal products is disaggregated into two sectors; Iron and steel and Metallic products fabrication except machinery and equipment.
(3) Electric, electronic and optical machinery and equipment is divided in 3 sectors: Electric machinery and appliances, Telecommunication equipment, Computers and other Electronic equipment and Office machinery, accountancy and computing machinery.
(4) Trade and Motor vehicles and reparation and personal and domestic use articles and Hotels and catering have been aggregated in Wholesale, detailed commerce, hotels and catering services.
(5) Service sectors are all included in Others.

Source: Own elaboration from CSEA and IPCC data.

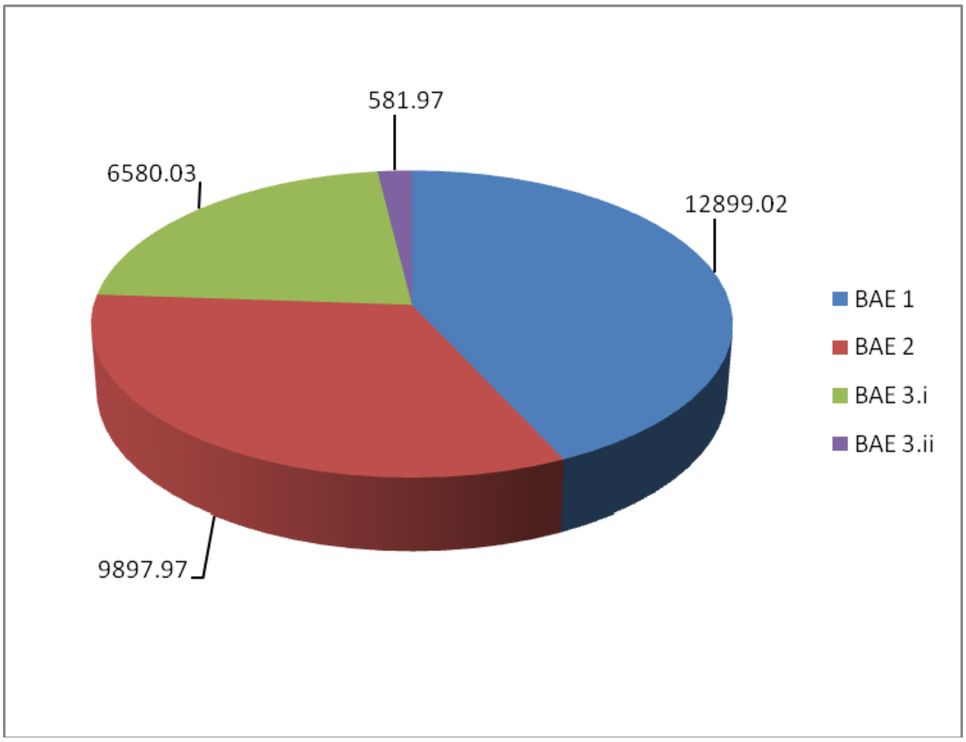
3.4 Spanish-Chinese trade and Pollution haven hypothesis

The study of Spanish-Chinese trade relationships shows a significant deficit in the emissions balance, mainly due to the large trade deficit between Spain and China and the differences between both countries polluting structures. With the development of the Balance of avoided emissions (BAE) we will be able to know if the existence of bilateral trade between Spain and China is beneficial or not for the global environment. We will only present results for 2005.

Figures show a positive result in this BAE which demonstrates that international trade between Spain and China generates a negative global environmental impact, since trade between both countries increases global emissions by 29,959 MtCO2. It therefore conforms to the Pollution Haven Hypothesis (PHH) between both countries. The result of this BAE for 2005 represents 48.95% of the total global emissions derived from the Spain-China trade. We can say that had this trade not occurred (so each country had produced its demand of final and intermediate goods), global emissions would have been restrained to about 50% of what they have actually increased.

The analysis of this BAE by components shows that 43.06% of this PHH correspond to imports of final goods (BAE 1), while 33.04% is due to imports of intermediate goods entering the last stage of production that is finally sold within our borders (BAE 2). As a result, more than 76% of those emissions of these emissions, derived from Spanish-China bilateral trade, correspond to imports of goods to attend the Spanish domestic final demand. The rest of the PHH is due to GVC, and they amount to nearly 24% of total emissions from such trade. These are Spanish imports of intermediate goods traded again to the rest of the world (China included). The high degree of detail presented in this BAE helps us to determine whether imports of intermediate goods we require for later export (without differentiating between final or intermediate exports) go to China or elsewhere. The results show how the Spanish-China GVC amounted to only 1.94% of total emissions avoided (BAE 3ii). However, the remaining 21.96% of the emissions correspond to exports of goods to the rest of the world (ROW, BAE 3i).

Figure 4: Decomposition of Spanish-China Balance of avoided emissions (2005), thousands of tons.

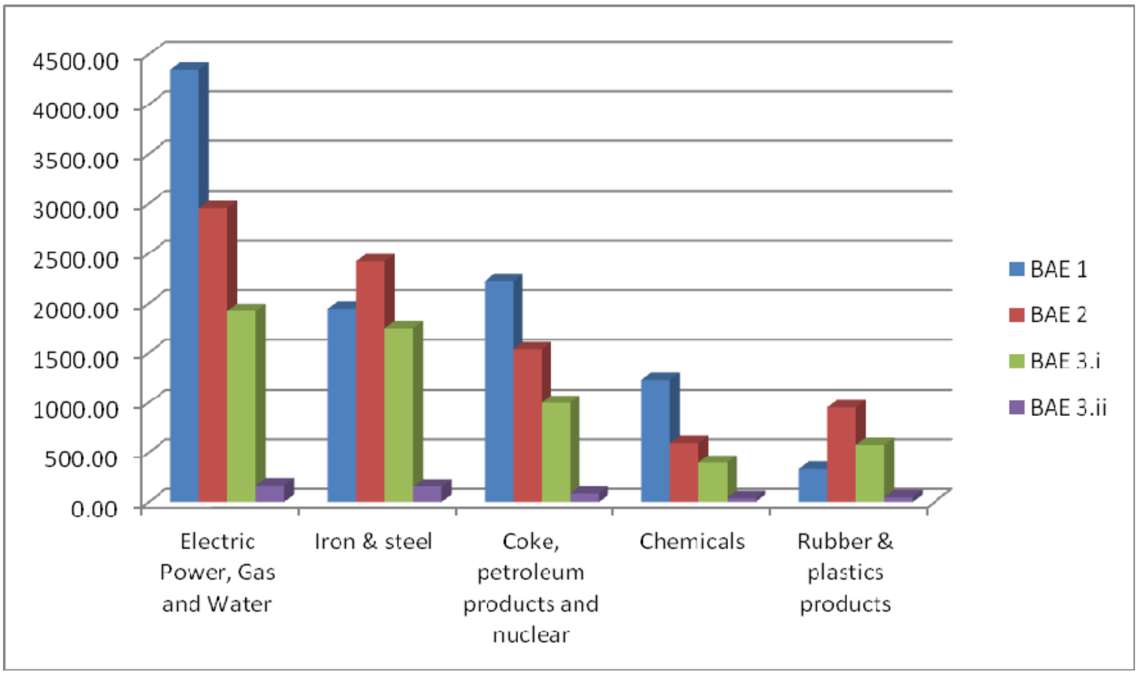


As described in the section on methodology, by working with matrices and vectors of final demand and diagonalised emissions, we are able to obtain a BAE in matrix form (23 x 23) for each component in the balance. This is why we can exhaustively analyse the balance by rows and by columns.

By rows or products, as can be seen in Figure 5, we can highlight a selection of five products with the highest PHH, expressed by their components in the BAE. International freight transport between Spain and China make Electric power, gas and water to be the industry with highest volume of PHH, 9,396.32 $MtCO_2$, that could have been avoided if all imported goods had been produced within the country. The second product with the highest PHH is Iron and steel, with emissions volume of 6,268.29 MtCO2. The third product in that ranking is Coke, petroleum products and nuclear fuels, 4,836.86 MtCO2. Chemical products and Rubber and plastic products are fourth and fifth, with 2,250.03 and 1,903.10 MtCO2 of non-avoided emissions, respectively. By BAE components, the distribution is similar for most products to that of the global economy, shown in Graph 4. More than 75% of non-avoided emissions are due to imported final or last-stage intermediate goods to attend Spanish domestic final demand. Only Iron and steel, and Rubber and plastic products, show a different composition, with a higher role for GVC (BAE 3i and BAE 3ii).

According to this analysis, we can conclude that the Spanish-Chinese trade is based on energy and input-intensive goods, or on goods that require intensively energy for their extraction and processing, as Iron and steel, or transformed from energy goods like Rubber and plastic products.

Figure 5: BAE analysis by rows, thousand tons.



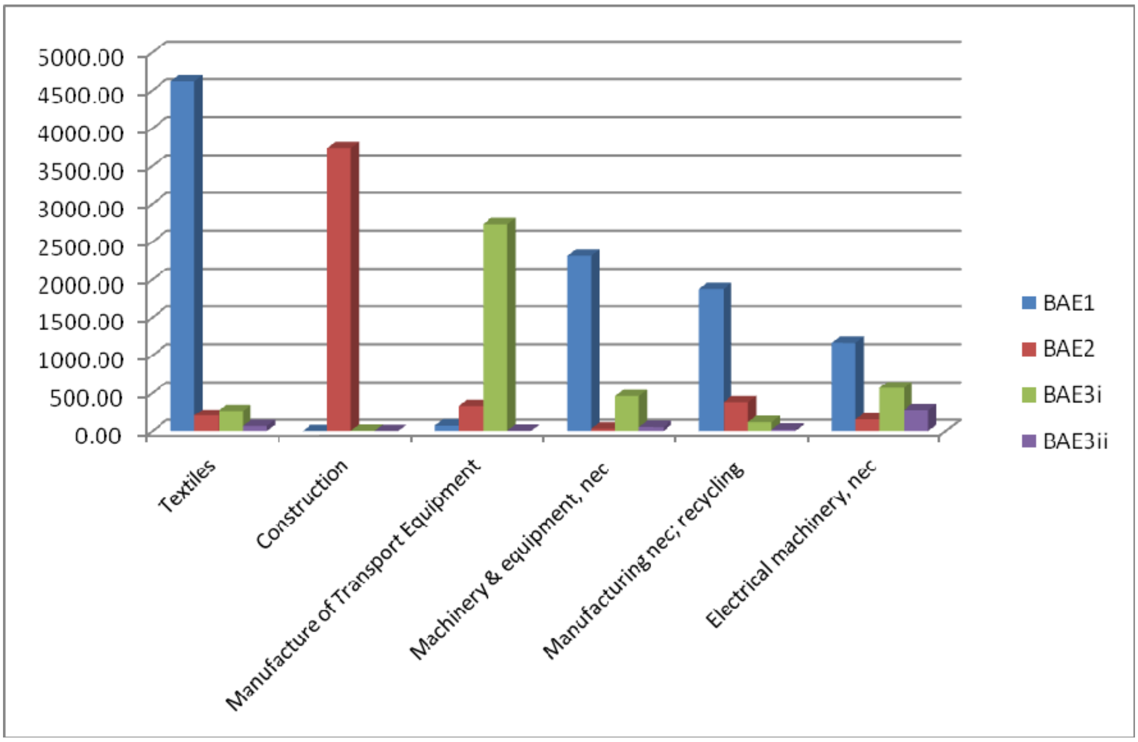
The columns or sectors analysis provides information about delocalising sectors, showing the Spain-China trade PHH sectoral composition accounting for goods final destination,

Figure 6 contains those sectors with higher PHH in 2005. It shows all the components within BAE in order to differentiate the environmental effect of the different uses of traded goods.

It is remarkable the textile industry PHH, 5,143.53 MtCO2 non-avoided, where most imported goods satisfy final demand (BAE1). Building is the second sector with higher PHH, 3,737.19 MtCO2 non-avoided. They are all devoted to the second BAE component, that is, emissions embodied in imported goods that fit into final goods sold to domestic demand, (BAE2). The third sector in BAE importance is Manufacture of transport equipment, with a PHH of 3,129.64 MtCO2 non-avoided emissions that go mainly to GVC, more specifically as exports to the rest of the world (BAE3.i). The forth sector in PHH importance is Machinery and equipment, with a total of 2,849.60 MtCO2 non-avoided, that go mainly to final demand. The fifth sector is Manufacturing & recycling, with a PHH of 2,386.17 MtCO2 non-avoided, and the sixth is Electrical machinery, with a PHH of 2153.27 MtCO2. The last two groups enter in the production of final goods.

The results show that sectors with higher PHH are among the most intensive in energy use, similarly to the results of the rows analysis of Figure 5.

Figure 6: BAE analysis by columns



4. Conclusions

The analysis in this paper allows us to state that China has become a pollution haven for the Spanish economy. Firstly, because the emissions balance between these two countries shows a negative balance for Spain of 61,200 ktCO_2, from a total of 62,000 ktCO_2 exchanged. Secondly, and more important, the balance of avoided emissions shows that almost 50% of those emissions, 29,000 ktCO_2, are due to the existence of international trade. This is explained by the high polluting intensity of the Chinese economy compared to Spain. In a world with no international trade each country would have to produce its imports and that would have avoided those 29,000 ktCO_2. When producing and selling, firms neglect the environmental impact of that production in both countries.

The main contribution of this work is that the methodology and data used, in a bi-regional context, has allowed us to differentiate our BAE measure by components, depending on whether the goods traded were final or intermediate, and on whether they attended domestic final demand or were re-inserted in GVC through exports. The four components of our equation are: BAE 1) final goods trade for both countries; BAE 2) trade of final round of intermediate goods to serve the domestic final demand in each country; trade of intermediate goods to serve the exported final demand of both countries (GVC), they can be to the Rest of the world (BAE 3.i) or to the country with which we trade bilaterally (BAE 3.ii).

By means of international trade between Spain and China profits are generated and shared by entrepreneurs, consumers, workers and governments through taxes in both countries. Nevertheless, besides these profits there are some losses due to the increase of CO_2 emissions that generate external effects for which nobody is held responsible. These agents must become, up to a point, responsible if our objective is to reduce the environmental impact from economic activity. Governments, through the design of appropriate policies, are the main agent: international agreements that progressively incorporate non-Kyoto-signatory countries in the line of Copenhagen, imposing CO_2 border taxes, promoting renewable energies in the production of electricity, designing ecological labels that would allow consumers to identify less polluting goods, etc.

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