Global emissions chains and multinational enterprises: measuring responsibilities following the control criterion

López, Luis-Antonio; Cadarso, María-Ángeles; Zafrilla, Jorge and Arce, Guadalupe

Luis.LSantiago@uclm.es; Angeles.Cadarso@uclm.es; Jorge.Zafrilla@uclm.es; Guadalupe.Arce@uclm.es

Faculty of Economics and Business, University of Castilla-La Mancha
Plaza de la Universidad, 1, 02071, Albacete, Spain

DRAFT VERSION OF THE PAPER

PLEASE, DO NO CITE WITHOUT THE PERMISSION OF THE AUTHORS

Abstract

The Kyoto Protocol framework establishes the Production-based (PR) criterion (IEA, 2001) as the emissions responsibility allocation method. Greenhouse Gases emissions (GHG) are assigned depending on the country where they occur, regardless of the country where the consumption is done. This approach has generated controversy and is the point at which many emerging and large exporting countries base their refusal to sign the emissions reduction international agreements. Emerging countries argue that they are adversely affected in a context where production and consumption decisions are increasingly separated in different parts of the world. Moreover, carbon leakage through international trade threatens national reductions achievements at global level. One of the most popular scientific literature on alternative approaches proposes to shift responsibility to the consumer (Peters and Hertwich (2008) or Davis et al. (2011)). A country would be responsible for the emissions generated in the production of goods that are consumed within its borders, independently where the goods or services are produced. However, the consumer responsibility criterion (CR) has not managed to become part of international environmental legislation yet, although it has the advantages of allocating higher emissions to outsourcing 'rich countries', which import highly polluting goods, and reducing the burden for the big-exporting countries, which are usually referred as "developing countries factories".

The global nature of climate change requires the establishment of allocation responsibility criteria that allow to involve more participant agents of different countries in the process: governments, consumers, suppliers, workers or investors (Hoekstra and Wiedmann 2014). Taking into account the presented context, in this paper a control-based criterion is proposed, previously presented in López et al. (2014b), in order to allocate the responsibility to the firms that take decisions, in many cases, of locating thousands of kilometres away in countries with weaker environmental policies. This criterion assign to those firms all the emissions embodied in linkage effects along the production chain. Taking into account the control criterion, the limits of enterprises' responsibility is not determined by the country's borders, this limit is given by the control that the parent companies has on its subsidiaries firms and suppliers too, regardless of geographical location and where are citizens of the world that are consuming the goods produced by these enterprises. Therefore it is necessary to find new frameworks that encourage more countries to sign emissions reduction international agreements and also that allow the responsibility transfer to companies and citizens as main actors' in the mitigation of climate change. To shift the focus to the role of companies, instead of nation-states, has some advantages as, for instance, not to deal with the problem of restricting responsibility to territory (PR) or of the ability of governments to act beyond their frontiers (CR). Moreover, recent research states that nearly two-thirds of historic emissions can be attributed to 90 companies (Heede 2014). Companies, and thus consumers, do not become knowledgeable about the environmental impacts of their production networks (O'Rourke 2014); these firms do not take responsibility for the external costs associated to these impacts. The quantification of these emissions under the control criterion and the allocation of responsibility to firms would help to provide positive incentives for the more efficient management in environmental terms of the global value chains by the companies.

The aim of this paper is to calculate a control-based criterion for China in a multiregional input-output context (MRIO), which allows the assessing of the impact of international trade considering all the emissions associated with the entire global value chains. The Chinese choice is due to foreign enterprises operating and exporting in China account for 54% (Feenstra et al. 2013) and have a strong potential influence over the global production chains with respect to technology and emission intensities (Skelton 2013). Estimations will be done using the World Input-Output Database (WIOD) that provides information about 41 regions with a sectorial disaggregation of 35 industries. These data will be combined with information about multinationals operating in China for the year 2009.

Previous results of the application of the control criterion was presented in López et al. (2014b), which compares the results presented in Lin et al. (2014) using a consumption-based assumption with a control-based approach show that, according to a control-based criterion, the United States is responsible for 65% more CO2, 68% more NOx oxides and 66% more SOx emissions than the results of consumer responsibility estimations held by Lin et al. (2014).

1. Introduction

The global nature of climate change requires the establishment of allocation responsibility criteria that allow to involve more participant agents of different countries in the process: governments, consumers, suppliers, workers or investors (Hoekstra and Wiedmann 2014). Taking into account the presented context, in this paper a national control-based accounting criterion is proposed, previously presented in López et al. (2014b), which is built from the firms or industries environmental responsibility whose capital is owned by a country's shareholders producing within or outside the borders. The nationality or origin of headquarter is used to allocate emissions by countries. Taking into account the control criterion, the limits of enterprises' responsibility is not determined by the country's borders, this limit is given by the control that the parent companies has on its subsidiaries firms and suppliers too, regardless to the geographical location and where are citizens of the world that are consuming the goods produced by these enterprises.

The Kyoto Protocol framework establishes the Production-based (PR) accounting criterion (UNFCCC 1992) as the country emissions responsibility allocation method. Greenhouse Gases emissions (GHG) are assigned depending on the country where they occur, regardless of the country where the consumption is held. This approach has generated controversy and is the point at which many emerging and large exporting countries base their refusal to sign the emissions reduction international agreements. Emerging countries argue that they are adversely affected in a context where production and consumption decisions are increasingly separated in different parts of the world. Moreover, carbon leakage through international trade threatens national reductions achievements at global level. One of the most popular scientific literature on alternative approaches proposes to shift to consumption-based accounting (Peters and Hertwich (2008) or Davis et al. (2011)). A country would be responsible for the emissions generated in the production of goods that are consumed within its borders, independently where the goods or services are produced. However, the consumer responsibility criterion (CR) has not managed to become part of international environmental legislation yet, although it has the advantages of allocating higher emissions to outsourcing 'rich countries', which import highly polluting goods by carbon leakage (Kanemoto et al. 2014), and reducing the burden for the big-exporting countries, which are usually referred as "developing countries factories".

Nearly two-thirds of historical CO_2 emissions and methane (1854-2010) can be attributed to 90 incorporated entities (50 leading investor-owned, 31 state-owned, and 9 nation-state). The majority of them produce oil, natural gas, coal and cement (Das and Paul 2014), which are mainly

used as inputs by the whole economy. This means that the environmental impacts of many industries are generated out of their borders through the purchase, direct and indirectly, of intermediate inputs to other firms, mainly from energy sector (López et al. 2014a). In this sense, Kagawa et al. (2015) identify the importance that a few number of clusters have, being part of the global supply-chains networks, over the total CO2 emissions related to the world wide economy final demand. To the extent that these impacts are within the core area of final demand supplier industries' influence (Skelton 2014), could, through the choice of suppliers (upstream) and distributors (downstream) more environmental friendly, reduce their carbon footprint, transfer technology to their suppliers in other countries and would help to the implementation of a greener global supply chain management.

The control-based accounting method allocate responsibilities to countries estimating the footprint generated by the decisions taken by industries or firms shareholder's, producing within or outside their political borders, or, in other words, through the estimation of the carbon footprint of their multinationals corporations. The multinationals carbon footprint is obtained from an industry-based accounting principle that follows the concept of vertically integrated sectors (Pasinetti 1973) and quantifies the virtual carbon, domestic and imported, embodied in the production of goods and services of a final demand supplier industry (domestic or foreign). To shift the focus to the role of companies/industries has several advantages. First, it allows to identify the whole global production chain of the industry and to quantify its environmental responsibility all along it, including indirect and imported inputs and independently if the final product of the industry is consumed domestically or abroad. Second, the advantage that once firm become knowledgeable about the environmental impacts of their production networks can take responsibility for the external costs associated to these impacts (O'Rourke 2014). Third, the scope of influence of the firm is not only their own production process but also those of their providers and our estimations give a measure about how much this implies. In addition, our approach is based on the assessment of the firm's environmental responsibility and shares the objectives that, at the enterprise level, international environmental certification initiatives based on LCA methodology, which allow these companies implement sustainable management of resources, are also trying to incorporate emissions across the global value chain. For instance, the 2013 GHG protocol manual proposes a measurement method for estimating the scope 3 of these firms (Dietzenbacher et al. 2013b).

From the country industries' footprint, we propose to isolate the part associated to the production of their outward multinationals and also the part of inward (foreign capital) producing in the territory. The control-based accounting method of a country is obtained from the industries' footprint operating in a country, plus the outwards multinationals footprint operating in other countries minus the inward multinationals footprint operating in the country analysed. The results is an emissions allocation criterion which complies with the conditions proposed in Kander et al. (2015) to be useful in terms of climate policy: sensitivity (responds to changes in the whole system efficiency or to changes in final demand), monotonicity (a country is not be able to reduce their national carbons footprints in ways to increased global emissions) and additivity (the sum of national emissions for all countries should be equal to total global emissions). The control-based criterion, in front of the producer criterion not to deal with the problem of restricting responsibility to territory, and in front to consumer criterion allow to reduce the problem of the lack of ability of governments to act beyond their frontiers (Cadarso et al. 2012).

Once multinationals know their carbon footprint, not only a sustainable management of it could be addressed, moreover, through certification mechanisms, they can transmit the information to consumers, who across their consumption decisions are able to guide the global economy on the path of sustainability. The proposed methodology pretends to differentiate the final consumers of goods produced by multinationals among the hosting multinational country, multinationals carbon footprint by hosting country, and the country that finally consume those goods, multinationals carbon footprint by consumer country. Furthermore, for a single country, we can have two different responsibility balances. On the one hand, for the country that hosts the multinationals, the difference between both measures results in an environmental responsibilities balance (emissions balance) of multinationals, in similar way we get it for the economy (Peters 2008), which allow us to evaluate the importance of international trade and the carbon leakage over the total amount of emissions which a country is responsible as owner (Davis et al. (2011), Peters et al. (2012)). A positive sign of this balance would indicate that those multinationals export more virtual carbon than the imported to supply the multinationals final demand, and vice versa. Those multinationals settled in a country to take advantage of low salaries, for instance, and oriented to export more than to the domestic market of the hosting country would show bigger negative hosting balances. On the other hand, we can obtained a responsibility balance in relation to the owner country c as the difference between the carbon footprint of multinationals of country *c* operating abroad and the carbon footprint of the foreign multinationals operating in country *c* territory. We can expect that the owner balance would be

quite balanced for developed and big countries, with firms that show leadership in some industries but at the same time big domestic markets that attract foreign firms as a way to have access to the domestic consumers.

The literature has also presented other alternative criteria such as the income-based responsibility (Marques et al. 2012), the criterion based on the consideration of the total stock of historical emissions produced by a country or region Vazhayil et al., 2011 and Álvarez and Gallego (2014) or a criterion which allocate emissions on individuals within countries (concerning the income distribution), and not on countries (Chakravarty et al. 2013). Some recent works such as Lenzen et al. (2007), Peters (2008) or Cadarso et al. (2012), suggest, as a solution to the responsibility assignation controversy, the adoption of shared responsibility criteria. This is an intermediate system between the production-based and consumption-based approaches that seeks to involve all agents that take part in the environmentally harmful production or consumption processes.

In this paper a MRIO model is developed in a context of limited statistical information which allow the accounting of a national control-based criterion focused on the estimation the US multinationals carbon footprint operating overseas (outward) and on the estimation of overseas multinationals operating in the US (inward) in 2009. Changes in US responsibility under the producer, consumer and control-based criteria, and the implications in mitigation policies are going to be addressed. To do that, we are going to integrate the statistical information provided by the US Bureau of Economic Analysis (BEA) about value added generated by outward and inward multinationals by industries in the USA (BEA Various years), in a MRIO model built with the World Input-Output Database (WIOD) that provides information about 41 regions and 35 industries (Dietzenbacher et al. 2013a).

2. Methodology

From producer responsibility to consumer responsibility

Nowadays, the input-output methodology to calculate the environmental responsibility of a country from the producer perspective (or production based emissions inventories) and from the perspective of the consumer (or consumption based emission inventories or carbon footprint) is well established, both theoretically (Wiedmann et al. (2007) and Kanemoto et al. (2012)) and empirically with a wide variety of applications. The relevance of both criteria rely on their ability to quantify the environmental burden and to identify and allocate the responsibility to the countries and, according to that, to define mitigation policies (Peters and

Hertwich 2008). According to the production-based accounting, emissions are allocated to the country where they occur. According to the consumption-based accounting, emissions are allocated to the country where the final goods are consumed and, therefore, through international trade the environmental responsibility is transferred among countries: the intermediate inputs become endogenous and all the virtual carbon embodied in final exports are allocated to consumer countries (Kanemoto et al. 2012). Nevertheless, within each country several agents are involved (firms that produces and consumes, investors, workers, households, public administrations) and among them, is necessary to look for criteria that allow to share the responsibility (Hoekstra and Wiedmann 2014), and widen the scope of suitable policies and, also, that allow to direct the focus of mitigation policies more effectively (Kagawa et al. 2015). This is the reason why we, in this paper, start from a concept we could consider an intermediate point between the concepts of production-based accounting and consumption based-accounting, which pays attention mostly to the industry and its needs of inputs (direct and indirect, including those imported) from producing its final product, or in other words, to the industry as a consumer of inputs (for production). Focusing on the industry responsibility on emissions, a principle we can call industry-based accounting (or industry carbon footprint, as we will see later on), we consider that we go a step further in the need of firms to achieve a sustainable management throughout their global production chains and then transfer their achievements to the consumers.

In the input-output framework, we obtain the responsibility on emissions according to the producer criterion and to the consumer one from the basic multiregional environmentally extended input-output model, represented in expression (1) (Wiedmann et al. (2007), Peters and Hertwich (2008)):

$$f = e(I - A)^{-1} y \tag{1}$$

Were $e(I - A)^{-1}$ is the emission multiplier. We will work with diagonal matrices of final demand and emission coefficients ($\hat{y}$ *and* $\hat{e}$, respectively), so we will obtain a matrix of emission multipliers (P) and a matrix of total emissions (F), as in expression (2):

$$F = P\hat{Y} \tag{2}$$

Where $\hat{Y}$ is the matrix of final demand, whose characteristic element y^{ij} shows final demand produced in country i and with destination to country j, where y^{ii} elements are shown in the

main diagonal while y^{ij} elements are shown in the off-diagonal positions. For example, for three regions we get:

$$\begin{bmatrix} F^{11} & F^{12} & F^{13} \\ F^{21} & F^{22} & F^{23} \\ F^{31} & F^{32} & F^{33} \end{bmatrix} = \begin{bmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{bmatrix} \begin{bmatrix} \hat{y}^{11} & \hat{y}^{12} & \hat{y}^{13} \\ \hat{y}^{21} & \hat{y}^{22} & \hat{y}^{23} \\ \hat{y}^{31} & \hat{y}^{32} & \hat{y}^{33} \end{bmatrix} \quad (3)$$

Where P^{rs} shows total emissions that occur in country r when attending a unit of final demand of country s, and F^{rs} is the equivalent for total emissions, but split up by country of origin and destination. Summing F matrix by rows results in total emissions (domestic) per production country ($PR = f^i = \sum_j F^{ij}$). This measure is a country's producer responsibility (PR) and it is the measure considered by the Kyoto Protocol for commitments of emissions reduction. Summing up along columns we have 'vertical integration by countries' (Pasinetti 1973) or emissions generated all over the world linked to one country's final demand ($CF = CR = f^j = \sum_i F^{ij}$). This measure is called consumer responsibility (CR) or carbon footprint (CF) and it quantifies total, di rect and indirect, emissions linked to the demand of final goods by the country's agents (households' consumption, investment and public administration consumption). Also, in equations (2) and (3) it is possible to distinguish between emissions (domestic and abroad) embodied in domestic final demand ($y^d=[y^{ii}]$) and emissions (domestic and abroad) embodied in final imports (or exports, $y^r=[y^{ij}]$). The results of equation (2) and (3) by columns show the CF, since we have emissions embodied in imports allocated to the country that consumes them.

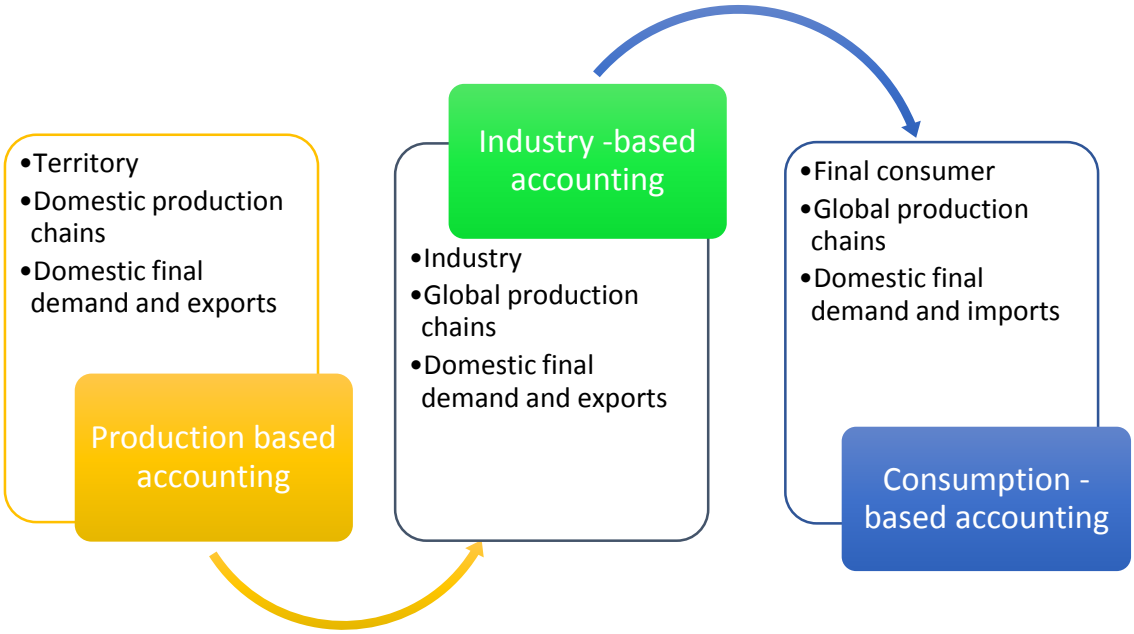
From producer responsibility to industry responsibility

The industry-based accounting quantifies the virtual carbon, domestic and imported, embodied in the production of goods and services that the industry provides to final demand[1]. The relevance of the criterion is related to its measurement of all the embodied emissions along the whole global production chain (not only the domestics ones, that are the only ones included in the production- based accounting) of both domestic production and exports (so not only the domestic and imported embodied in the consumption of the country, that are included in the consumption based-accounting, but also the emissions of the GPC linked to exports). The relation among these accounting principles is shown in Diagram 1. As a consequence, las

[1] See the papers: Sánchez-Choliz and Duarte (2005) and Cadarso et al. (2012) where in a single-region framework, the industries' responsibilities are analysed in a similar way we propose, taking as reference the VIS. On the other hand, the paper Skelton (2013) with a MRIO framework evaluates different attributions to industries responsibilities considering both the production of final and intermediate goods.

empresas de esa industria disponen de control sobre la propiedad y pueden establecer una gestión sostenible no solo sobre su propio proceso de producción sino también sobre sus suministradores y sobre toda su CGP, eligiendo suministradores directos eficientes y ejerciendo presión para que éstos a su vez elijan mejores procesos y mejores suministradores y así sucesivamente, y transmitiendo posteriormente esa información a los consumidores finales.

Diagram 1. Accounting principles of environmental responsibilities.



Source: own elaboration.

In the industry-based accounting, the allocation of environmental responsibility is on the producer industry, then. We calculate this by modifying the final demand matrix in expression (2) and (3), more specifically, by changing the position of imports in the final demand matrix to the main diagonal and summing up imports by country of origin, as is shown in equation (4):

$$\bar{F} = P\hat{y} = \begin{bmatrix} \bar{F}^{11} & \bar{F}^{12} & \bar{F}^{13} \\ \bar{F}^{21} & \bar{F}^{22} & \bar{F}^{23} \\ \bar{F}^{31} & \bar{F}^{32} & \bar{F}^{33} \end{bmatrix} = \begin{bmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{bmatrix} \begin{bmatrix} \hat{y}^{1\cdot} & 0 & 0 \\ 0 & \hat{y}^{2\cdot} & 0 \\ 0 & 0 & \hat{y}^{3\cdot} \end{bmatrix} \quad (4)$$

In expression (4) we have just diagonalised the row sum of Y matrix ($y = \sum_j y^{ij}$) and $\hat{y}^{i\cdot}$ stands for the final demand produced in country i (with destination to country i and the rest of countries and regions). Equation (4) shows the same amount of emissions by country (and sector) as equation (3) when summing along the rows ($PR = f^i = \sum_j F^{ij} = \sum_j \bar{F}^{ij}$), so both show the

same total PR by country (and sector). However, the results by columns are different, since we have a different allocation of emissions embodied in imports. Summing down the columns in expression (3) we have emissions embodied in the vertical integrated sector (Pasinetti 1973), in other words, we have direct and indirect emissions embodied in the inputs, and the inputs of the inputs, and so on, domestic and imported, required for attending the sector final demand (domestic and exported). We can consider that expressions (3) and (4) by rows take the territory as the key for defining the emissions responsibility (and, accordingly, we obtain the measure of PR), while expression (3), by columns, take the firm or the industry as the key element for defining the responsibility (and the measure we obtain is the firm or industry responsibility as a consumer). We call this later measure Industry Carbon Footprint (ICF= $I^j = \sum_i \overline{F}^{ij}$) and it traces total emissions embodied all the inputs directly and indirectly required in the production of final demand goods of every sector in every country, or in other words, total emissions through each stage of production along the global production chain. The industrial attribution of this measure shares the advantages for the calculation of carbon footprints, shown by (Lenzen 2008), specially the lack of double counting and truncation problems, and the downsides, specially those related to the data aggregation.

The industry carbon footprint measure shares with the usual measure of carbon footprint or CR the endogen character of intermediate commodities and their allocation to the consumer industry instead of to the consumer one. The difference between this measure ICF (columns sum of expression 4) and the usual CF (columns sum of expression 3) is that in ICF we have emissions embodied in exports allocated to the country and sector of production, while in CF we have emissions embodied in exports allocated to the country of destination (or consumption). Consequently, in ICF we have emissions directly and indirectly embodied in the production of the industry exports, while in CF these emissions are allocated to the country of destination, so in CF we only have emissions embodied in the final demand consumed by the country. The industry criterion shares with the producer one the allocation of virtual carbon to the country where the industry operates and they differ in the inclusion of imported emissions and, as a result, emissions from the whole production chain by the former (see also Diagram 1).

Outward MNs of country c

The industry carbon footprint is the starting point that allows us to focus on one country multinationals corporations (the multinationals, MNs from now onwards, that are property of the country) to assess and quantify the relevance of them in the ICF. It is relevant to identify the property, distinguishing it from the territory of operation in two ways. First, since, although the

emissions are allocated to the country of production, the control of production and decisions are taken by the owners of the capital, by the head-quarters, so they are who can take actions to reduce the carbon footprint of their corporation. Second, because identifying the relevance of MNs we identify their responsibility on emission throughout the whole global production chain and as a result, their scope of affecting emissions not only related to their own production process but also to those of their providers.

The procedure we propose here for the calculation of the MNs carbon footprint (MNCF) focuses on the MNs property of a single country c and it is conditional on the lack of information about technology and trade flows of intermediate and final products from and to MNs around the world. This lack leads us to take, as a first estimation, the simplest procedure, that is, to allocate to MNs emissions depending on the presence of MNs of one country in every sector of every country (recorded in percentage terms in vector m_O^c). This implies that MNs and the national industries share the same technical structure and the same share of imports and exports, which constitutes a limitation of the analysis[2]. Even though, the following calculations provide the measure of MNCF in this counterfactual (similarly to Dietzenbacher and Mukhopadhyay (2007), López et al. (2013), Liu et al. (2013)), if both industries the domestic ones and MNs would share the same characteristics.

Expressions (3) and (4) are the starting point for the calculation of MNCF, which means the emissions embodied in the outward MNs of a country *c*, and as a result we will obtain two different allocation criteria. Following expression (3), we obtain the MNCF of outward MNs of country *c* allocated by hosting country (MNCF-H) or, in other words, allocated to the sector and country where the production is happening, as is showed in expression (5):

$$OMNCF_H = \hat{e}(I - A)^{-1}\hat{m}_O^c\hat{y} = P\hat{m}_O^c\hat{y} \qquad (5)$$

Where $\hat{m}_o^c$ stands for the diagonalised matrix of the percentages of every sector production that comes from the outward MNs (indicated by the subscript O) of country c (indicated by the superscript c, being c=1…r) operating in every country all over the world. Obviously, matrices $\hat{m}_o^c$ and $MNCF_H$ show zeros from 1 to n sector positions of country c. For the three region example, expression (5) becomes:

[2] Two strategies have been used to evaluate/reduce the importance of this usual assumption of considering the average of the representative sector or firm to allocate environmental responsibilities: a) Authors like Lenzen (2011) and Su and Ang (2010) have evaluated how results change when a sector aggregation or disaggregation is held; b) Other researchers have developed hybrid LCA and Input-Output models Zafrilla et al. (2014) or Hertwich et al. (2014) and Weinzettel et al. (2014) obtaining better results for hybrid models than with MRIO models.

$$OMNCF_H = \begin{bmatrix} \bar{O}^{11} & \bar{O}^{12} & \bar{O}^{13} \\ \bar{O}^{21} & \bar{O}^{22} & \bar{O}^{23} \\ \bar{O}^{31} & \bar{O}^{32} & \bar{O}^{33} \end{bmatrix} \tag{6}$$

$$= \begin{bmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{bmatrix} \begin{bmatrix} \hat{m}_O^{c1} & 0 & 0 \\ 0 & \hat{m}_O^{c2} & 0 \\ 0 & 0 & \hat{m}_O^{c3} \end{bmatrix} \begin{bmatrix} \hat{y}^{1\cdot} & 0 & 0 \\ 0 & \hat{y}^{2\cdot} & 0 \\ 0 & 0 & \hat{y}^{3\cdot} \end{bmatrix}$$

Where $\hat{m}_O^{ii}$ will be zero. As a result, from expressions (4) and (5) we have the country *c* MNs carbon footprint all over the world. For instance, as we are going to focus on the United States of America (USA) in the empirical part, USA is country c, so $OMNCF_H$ shows the carbon footprint of USA's MNs read around the world allocated to the hosting country, so it shows emissions of USA MNs settled in China, Australia or France. It is not properly a carbon footprint, since the emissions of MNs are allocated to the producing country (the hosting country) instead of to the consumer country, as the definition of carbon footprint would require. This means, for example, that emissions embodied in goods produced by USA MNs in China, but then exported and consumed in Spain are allocated to China instead of being allocated to Spain, according to $OMNCF_H$ measure. A "pure" carbon footprint would require that the responsibility of those emissions falls in Spain, since it is the consumer country.

The "pure" consumption responsibility and, consequently, the carbon footprint, on the other hand, is obtained if we follow expression (3). Starting from there, we obtain the MNCF of outward MNs of country c allocated to the countries that finally consume the goods (MNCF-C) as is shown in expression (7):

$$OMNCF_C = \hat{e}(I - A)^{-1}\hat{m}_O^c\hat{y}^{ii} + \hat{e}(I - A)^{-1}\hat{m}_O^c\hat{y}^{ij} = P\hat{m}_O^c y^d + P\hat{m}_O^c y^r \tag{7}$$

Where y^d is final demand produced and consumed domestically and y^r is final demand exported (imported). The only difference in relation to expression (4) is that we have included the final demand as in expression (2), so we have final demand allocated by columns to the country of destination (consumption). In addition, we have split final demand up distinguishing between domestic final demand and exported/imported final demand. In the three region example we have:

$$\begin{bmatrix} O^{11} & O^{12} & O^{13} \\ O^{21} & O^{22} & O^{23} \\ O^{31} & O^{32} & O^{33} \end{bmatrix}$$

$$= \begin{bmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{bmatrix} \begin{bmatrix} \widehat{m}_O^{c1} & 0 & 0 \\ 0 & \widehat{m}_O^{c2} & 0 \\ 0 & 0 & \widehat{m}_O^{c3} \end{bmatrix} \begin{bmatrix} \hat{y}^{11} & 0 & 0 \\ 0 & \hat{y}^{22} & 0 \\ 0 & 0 & \hat{y}^{33} \end{bmatrix} \quad (8)$$

$$+ \begin{bmatrix} P^{11} & P^{12} & P^{13} \\ P^{21} & P^{22} & P^{23} \\ P^{31} & P^{32} & P^{33} \end{bmatrix} \begin{bmatrix} \widehat{m}_O^{c1} & 0 & 0 \\ 0 & \widehat{m}_O^{c2} & 0 \\ 0 & 0 & \widehat{m}_O^{c3} \end{bmatrix} \begin{bmatrix} 0 & \hat{y}^{12} & \hat{y}^{13} \\ \hat{y}^{21} & 0 & \hat{y}^{23} \\ \hat{y}^{31} & \hat{y}^{32} & 0 \end{bmatrix}$$

Summing along the rows the $OMNCF_C$ matrix we have the same result than summing along the rows of $OMNCF_H$, both for sectors and countries, but the total for countries and sectors are different when we sum down the columns, because of the different allocation criterion. The first component of the second part of expression (8) shows total emissions owed to country c MNs that attends the domestic final demand of the hosting country allocated by consumer country (hosting country also, in this case) while the second element shows total emissions owed to exported/imported final demand of country c MNs all over the world allocated by consumer country (which is different from the hosting country, in this case). Expressions (6) and (7) would allow for different shares of MNs depending on the export orientation degree of the MNs. However, in the paper we are not considering if the MNs are producing for the domestic demand or for exports, since we consider the same share of MNs in both cases. Moreover, we consider that MNS have the same production structure of the hosting country, also in terms of imports. The possibility of different technical structure for MNs would imply to change the matrix P, changing the Leontief Inverse accordingly. This could be done taking the technical structure of the country of origin of MNS. Additionally, the literature on processing and non-processing exports argue that the former firms are not connected with the domestic country and that all the inputs used are then imported (Su and Ang (2013) and Xia et al. (2015)).

Inward MNs of country c

The CF of MNs from everywhere operating in the country c can be obtained from expressions (4) and (6) changing the matrices of outward percentages by a matrix of inward percentages, or in other words, by share of the MNs from all the countries that are settled in every sector in one single country. As in the outward MNs we can obtain the inward carbon footprint of MNs (IMNCF) by two different allocations, by hosting country ($IMNCF_H$) and y consumer country ($IMNCF_C$) as is shown in expressions (9) and (10), respectively:

$$IMNCF_H = \hat{e}(I - A)^{-1}\widehat{m}_I^c\hat{y}^{i\cdot} \quad (9)$$

$$IMNCF_C = \hat{e}(I - A)^{-1}\hat{m}_I^c\hat{y}^{ii} + \hat{e}(I - A)^{-1}\hat{m}_I^c\hat{y}^{ij} \quad (10)$$

Both expressions show the same global amount and the same totals by rows, but not by columns because of the different allocation criterion. $MNCF_H$ allocates the responsibility of emissions embodied in the production of the rest of the world MNs settled in one country to the hosting country where the production has happened, while $MNCF_C$ allocates the responsibility of emissions to the countries that are going to consume the goods produced by the MNs.

Control-based responsibility criterion.

Multinational corporations are spread around the world and are one of the engines of globalization. They should be aware of their power in spread innovation and environmental responsibility.

The previous calculations of the carbon footprint of MNs allow us to assess how the responsibility of a country changes when we take into account both their MNs operating overseas (outward MNs), which would increase the emissions responsibility burden of the country, and other's countries MNs operating within their territory (inward MNs), which would decrease the country responsibility on emissions. We call the resulting responsibility Control Criterion (CC), since it focuses on whose is the property and, as a result, the control ability of the firm. This measure of responsibility can be calculated from the producer responsibility measure or from the consumer one, as is shown is expressions (11) and (12), respectively:

$$CC = \overline{F^c} + OMNCF_H * I^{1j} - IMNCF_H \quad (11)$$

$$CC = F^c + OMNCF_C * I^{1j} - IMNCF_C * I^{1c} \quad (12)$$

Where all the matrices has the dimension nx(nxr), $\overline{F^c}$ is a matrix that collects the industry carbon footprint of every sector in country c, I^{1j} is a matrix of identity matrices in the positions 1j (j=1…r), and I^{1c} is a matrix of zeros with ones in the main diagonal of sector positions of country c (or an identity matrix only in the position 1c). The procedure for achieving the CC measure only allows us to obtain the control responsibility linked to a single country and it not implies a similar measure for the rest of countries, since we do not distinguish in the IMNCF the country origin of the MNs involved.

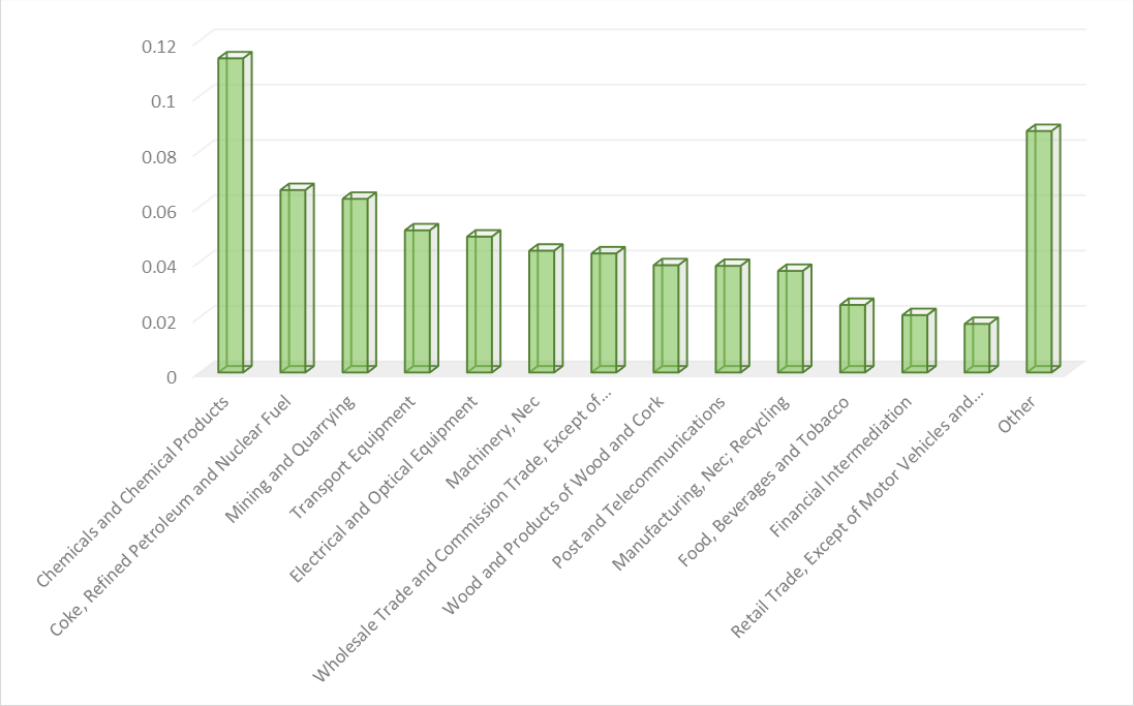
3. Main results.

3.1. Integration of BEA Outward and Inward Multinationals Value Added and WIOD Value Added by Industries.

The cornerstone of this paper is the estimation of the multinationals footprint of a country. We have chosen the Value Added (VA) generated by multinational firms to do the estimation. There is a lack of reliable statistical information which provides so detailed information by countries and sectors. To present the control-based criterion and an empirical conclusion we have decided to focus only in the case of USA as the Bureau of Economic Analysis (BEA) of the USA provides detailed information of US multinationals operating abroad as well as foreign multinationals operating within the USA (BEA Various years) .

For the case of outward US multinationals operating abroad, Figure 1 shows the percentage by sector, on aggregate terms, that we have considered as US multinational share of emissions that have to be added to the US emissions responsibility and detracted to the rest of the world. We have matched the information provided by the BEA in terms of US multinationals VA, by sector and origin country, generated and we have divided it by the total VA per industry, by country, provided by the WIOD. Figure 1 does not show the disaggregation among countries, but the richness of information provided by both databases allow us to work with information for 41 countries with 35 sectors per country. On aggregate terms, the industries where the US multinationals have a greater presence worldwide are: Chemicals (11.3%), Coke and Refined Petroleum (6.6%), Mining and Quarrying (6.2%), Transport Equipment (5.1%) and Electrical and Optical Equipment (4.9%). The presence of US multinationals around the world is very high as aggregate figures show.

Figure 1. Percentage of US Outward Multinationals Value Added by Industry.

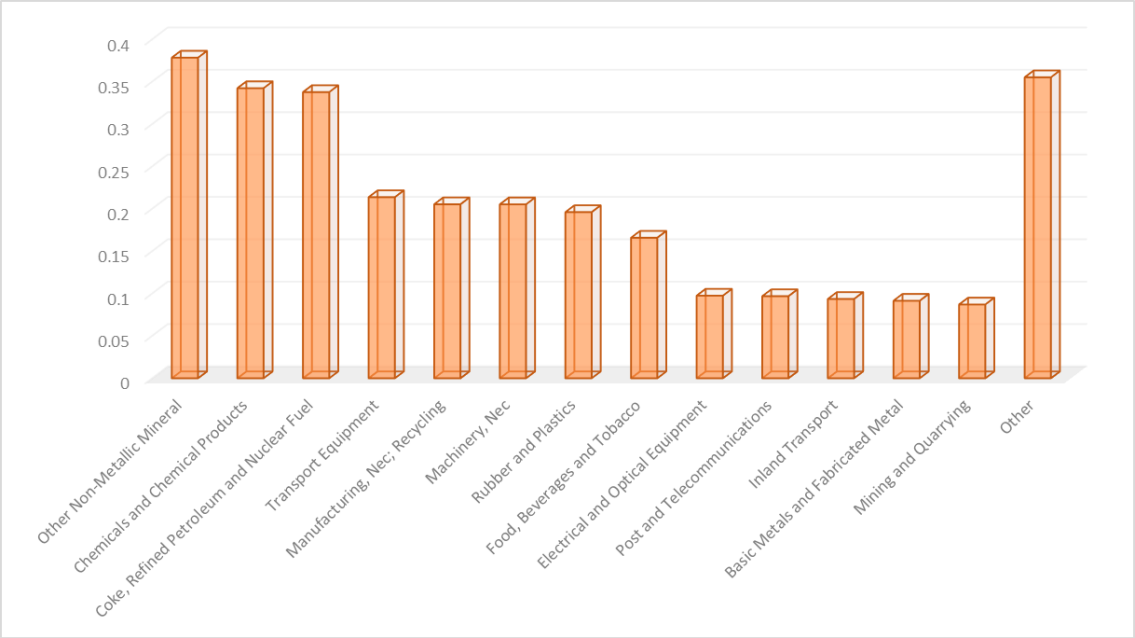


Source: Own elaboration.

Figure 2 presents the opposite, the percentage of VA generated in the USE by foreign multinationals divided by the same figures than in previous Figure 1, the total VA generated in the USA provided by the WIOD. This inward multinationals emissions are going to be detracted to USA responsibility in order to have a proper control-based accounting. Where the USA are not going to be responsible of the emissions generated by multinationals headquartered overseas.

In this case, the US industries with a greater presence of foreign multinationals are Other non-metallic minerals (37.8%), Chemicals (34.2%), Coke and Refined petroleum (33.7%) or Transport Equipment (21.3%). The US economy presents some determinant characteristics as its huge economic size. The presence of foreign multinationals is high due to the great domestic US market. This high figures in terms of foreign multinationals per unit of industry VA are going to detract a big amount of emissions per industry, also considering that USA is an emissions intensive country placed above the world average (Kander et al. 2015). The US control criterion is going to be balanced by all those economic features.

Figure 2. Percentage of US Inward Multinationals (foreign capital) Value Added by Industry.



Source: Own elaboration.

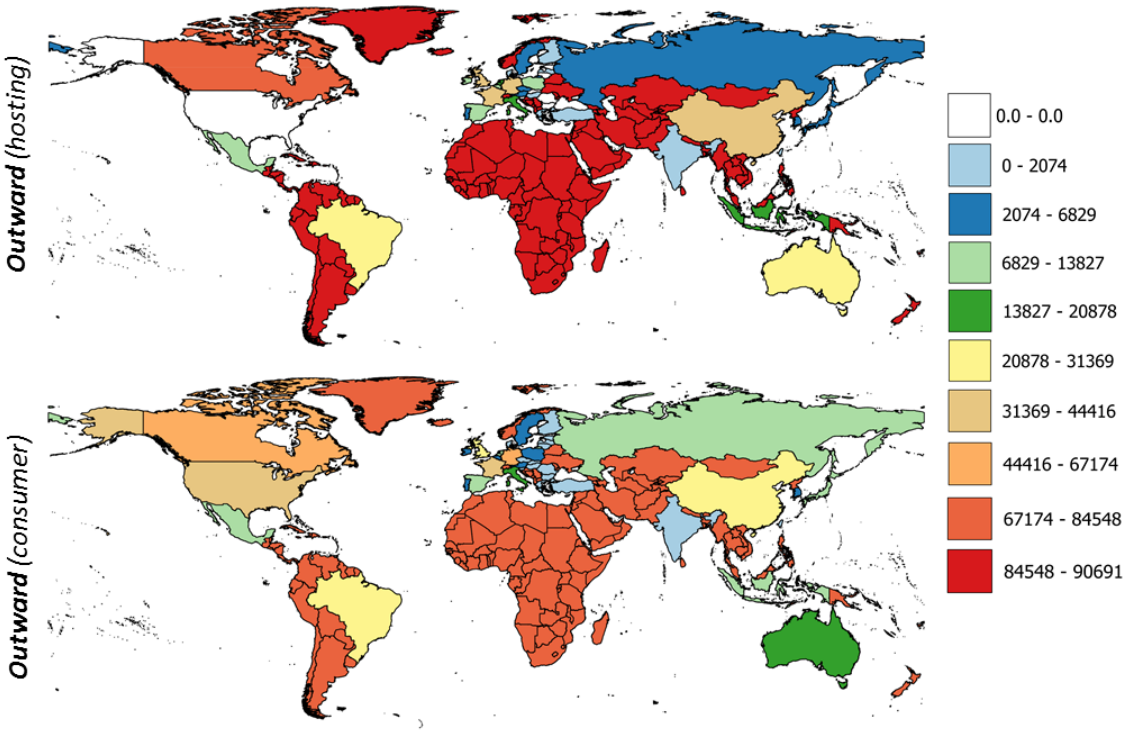
3.2. Measuring the carbon footprint of US multinationals.

Carbon footprint of US multinationals enterprises beyond its borders (outward) reached 0.527 $GtCO_2$ in 2009, which would lead an increase of 10% in the producer responsibility of the US (5,183 $GtCO_2$), an increase of 8.7% on the consumer criteria (6,035 $GtCO_2$) and an increase of 1.5% of the total CO_2 emissions in the world economy in 2009. Nevertheless, the distribution of the carbon footprint of multinationals by country can be measured on two criteria: according to the country that hosts the production and the country that finally consume the goods and

services. Figure 3 shows the carbon footprint of multinationals according to these two criteria. The most important hosting economies in terms of carbon footprint are the Rest of the World and Canada, representing 33.4% of total emissions, and followed by Germany, France and United Kingdom, between 43,415 and 38,696 $KtCO_2$. On the other hand, the countries responsible as consumers of the carbon footprint of multinationals are Canada, Germany, US, France and United Kingdom, nearly the same as the hosting criteria.

The colour change in Figure 3 in US indicates the emissions of its multinationals enterprises abroad, taking into account both criteria, hosting and consumer. As the figure refers only to outward, under the hosting criterion US would have zero emissions, which is indicated by the white colour. Under the consumer assumption, it is obtained that 8.4% (44,415 $KtCO_2$) of the carbon footprint of US multinationals outside its territory return to the American economy through goods and services which are finally consumed inside. The colour of Figure 3 is largely determined by environmental efficiency of US multinationals (CO_2 emissions per dollar of value added generated), which is very low compared to others developed economies. The inefficiency of the American economy is such that it presents very similar values to developing countries.

Figure 3. Carbon footprint of US multinationals enterprises, 2009 ($KtCO_2$).



Source: Own elaboration.

The calculation of emissions from these two criteria for US multinationals allow us to calculate a responsibility balance of multinationals. Analysing these differences between hosting and consumer criteria, if this discrepancy is positive would indicate that multinationals export more virtual carbon that are importing to supply the final demand of the products of the multinational companies. This is the case of Canada, with a discrepancy of 25.3%, and large economies in general, except Germany whose discrepancy reaches 11.9%, indicating that the final consumption of products from US multinational generates a higher carbon footprint than the production associated with multinationals in its territory. Most economies, 26 of the 41 considered, import more multinational emissions than they produce in their territory and the differences are significant especially in small economies where there is practically no presence of US multinationals. Therefore, the results found for US are as expected because the owner balance would be quite balanced for developed and big countries, with firms that show leadership in some industries but at the same time big domestic markets that attract foreign firms as a way to have access to the domestic consumers.

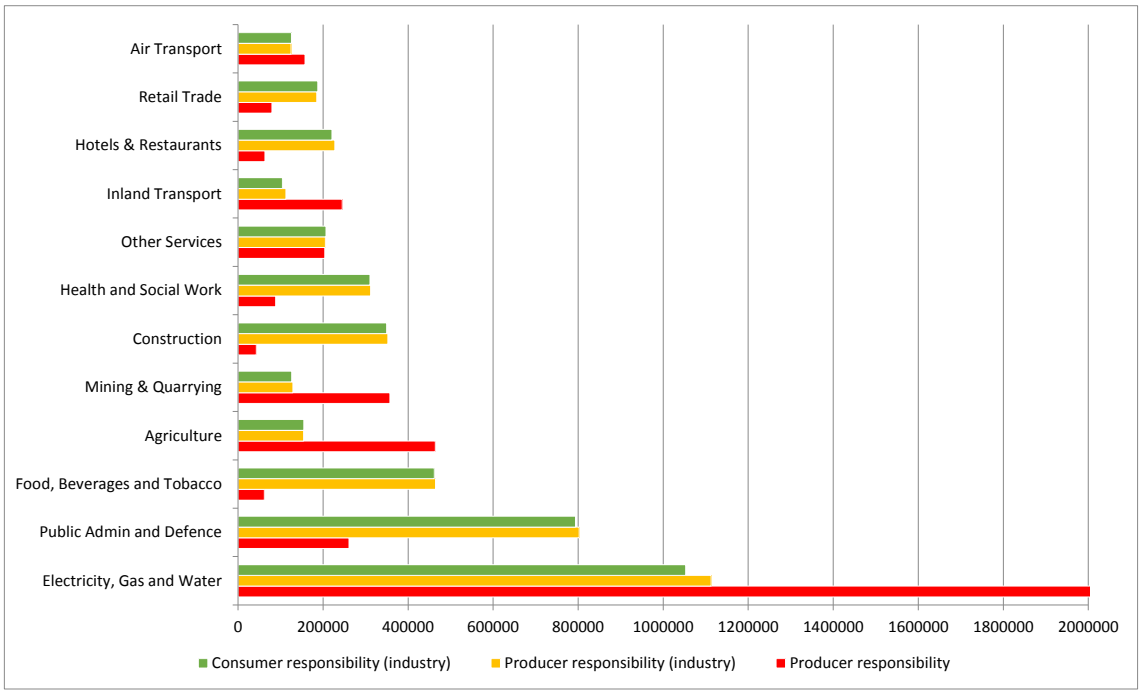
3.3. Accounting emissions under control criterion.

From the carbon footprint of US multinationals, the control-based accounting of emissions is obtained from the carbon footprint of industries operating in US, adding carbon footprint of US multinationals in other countries and subtracting the carbon footprint of multinationals from other nations installed in its territory. Therefore, this criterion for calculating emissions focuses on property of the multinationals and their nationality. And therefore, their ability to control where they settle down, being able to evade environmental responsibility if they leave to countries with less stringent legislations (even if they are only seeking advantages in labour costs, for example).

This measure of responsibility can be calculated from the producer responsibility measure or from the consumer one. As is described in the methodology section, to be able to measure the responsibility in the production process we need to develop an industry-based accounting method in order to measure all the embodied emissions along the whole global production chains and not only the domestic ones, due to the need of firms to achieve a sustainable management throughout their global production chains. Therefore, this is an approach that is able to identify the enterprise as the key element for defining the Responsibility. Figure 4 shows the discrepancies among the classical producer responsibility and the consumer and producer responsibility at industry level in a selected sectors. It can be seen as some industries as Electricity, Gas and Water supply; Agriculture; Mining and Quarrying or Inland and Air Transport

decrease their responsibility when we consider the industry-based accounting compared to production-based accounting. On the other hand, sectors as Public Administration and Defence; Food, Beverages and Tobacco; Health and Social Work or Hotels and Restaurants increase their responsibility when their emissions are calculated under the industry-based approach. However we can find industries where the results of accounting emissions under different approaches are very similar, as in the case of other services.

Figure 4. Comparing the different accounting principles of environmental responsibilities in US by sectors ($KtCO_2$).



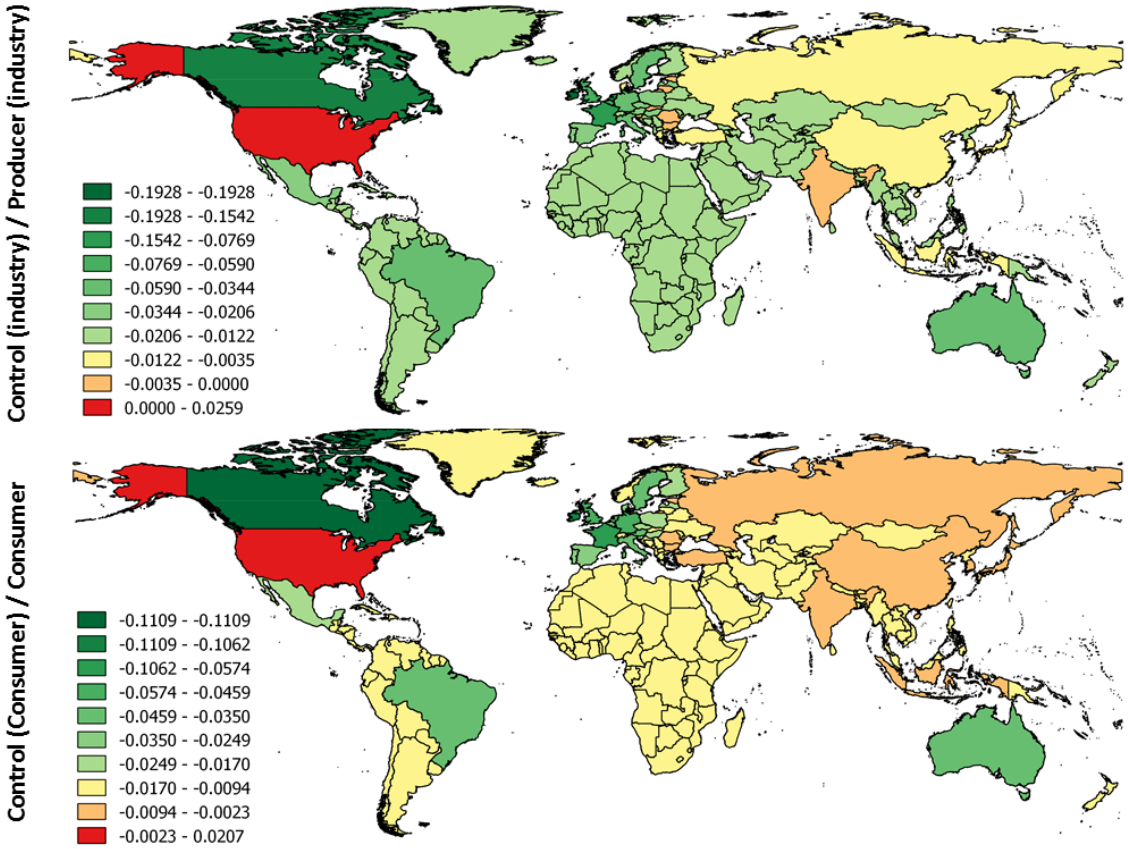
Source: Own elaboration.

Under the control criterion, the emissions responsibility of US increases with respect to the producer-industry approach and the consumer responsibility while the rest of economies decrease their responsibility. Previous results of the application of the control criterion was presented in (López et al. 2014b), which compares the results presented in Lin *et al.* (2014) using a consumption-based assumption with a control-based approach show that, according to a control-based criterion, the United States is responsible for 65% more CO_2, 68% more NOx oxides and 66% more SOx emissions embodied in trade with China than the results of consumer responsibility estimations held by (Lin et al. 2014).

In Figure 5 are shown the differences between control criterion and the rest of criteria considered. Is not surprisingly, because this paper is focused on the case of US, that only the US is increasing its responsibility (in red in both cases), and not very significantly (2.07% compared with consumer responsibility and 2.59% compared with producer-industry approach). These

small changes can be explained by the large size of the US economy and the huge size of its market, therefore, not only establishes multinationals abroad, but it hosts other companies in its territory (outward component is almost compensated by the inward). On the other hand, countries that reduce their responsibility more significantly are Canada (11.1% compared with consumer responsibility and 15.4% compared with producer-industry) and Ireland (10.6% and 19.3% respectively), following by France, Luxembourg and United Kingdom.

Figure 5. Emissions responsibilities change between control criterion, producer-industry and consumer responsibility. Parts per unit.



Source: Own elaboration.

4. Conclusions.

Producer versus Consumer responsibilities discussion is overtaken. The search and identification of new agents responsible of global emissions increase, in order to fulfill the target of immerse as much countries involved in international agreements as possible, is a necessity. Recent literature have provided a big number of alternatives following these target. In this paper we propose the estimation of a control-based criterion which tries to allocate responsibilities among multinational firms, which those who take the decision of outsource some parts of global

production chains to countries with weak environmental responsibilities, which is a driver of the global increase of GHG emissions. This paper is focused in the case of the USA.

Matching the information provided by the BEA about the VA generated by outward US multinationals around the world and about the inward foreign multinationals operating in USA, with the information about VA per industry taken from WIOD, we estimate the control-based criterion for the USA case.

Results show that carbon footprint of US multinationals enterprises beyond its borders reached 0.527 $GtCO_2$ in 2009, leading an increase of 10% in the PR of the US (5,183 $GtCO_2$), an increase of 8.7% on the consumer criteria (6,035 $GtCO_2$) and represents 1.5% of the total CO_2 emissions in the world economy in 2009. The main US multinationals hosting economies in terms of carbon footprint are the Rest of the World and Canada, representing 33.4% of total emissions, and followed by Germany, France and United Kingdom, between 43,415 and 38,696 $KtCO_2$. On the other hand, the countries responsible as consumers of the carbon footprint of multinationals production of goods and services are Canada, Germany, US, France and United Kingdom, nearly the same as the hosting criteria.

Under the control criterion, the emissions responsibility of US increases with respect to the producer-industry approach and the consumer responsibility while the rest of economies decrease their responsibility. US is increasing its responsibility, and not very significantly (2.07% compared with consumer responsibility and 2.59% compared with producer-industry approach). These small changes can be explained by the large size of the US economy and the huge size of its market.

5. References.

BEA. Various years. International Data: Direct Investment and MNE. *Bureau of Economics Analysis (BEA). U.S. Department of Commerce*.

Cadarso, M.-Á., L.-A. López, N. Gómez, and M.-Á. Tobarra. 2012. International trade and shared environmental responsibility by sector. An application to the Spanish economy. *Ecological Economics* 83: 221-235.

Chakravarty, D., S. Dasgupta, and J. Roy. 2013. Rebound effect: how much to worry? *Current Opinion in Environmental Sustainability* 5(2): 216-228.

Das, A. and S. K. Paul. 2014. CO2 emissions from household consumption in India between 1993–94 and 2006–07: A decomposition analysis. *Energy Economics* 41(0): 90-105.

Davis, S. J., G. P. Peters, and K. Caldeira. 2011. The supply chain of CO_2 emissions. *PNAS* 108(45).

Dietzenbacher, E. and K. Mukhopadhyay. 2007. An Empirical Examination of the Pollution Haven Hypothesis for India: Towards a Green Leontief Paradox? *Environmental & Resource Economics* 36(4): 427-449.

Dietzenbacher, E., B. Los, R. Stehrer, M. Timmer, and G. de Vries. 2013a. THE CONSTRUCTION OF WORLD INPUT–OUTPUT TABLES IN THE WIOD PROJECT. *Economic Systems Research* 25(1): 71-98.

Dietzenbacher, E. L., M., B. Los, D. Guan, M. L. Lahr, F. Sancho, S. Suh, and C. Yang. 2013b. Input-Output Analysis: The next 25 years. *Economic System Research* 25(4): 369-389.

Feenstra, R. C., C. Hong, H. Ma, and B. J. Spencer. 2013. Contractual versus non-contractual trade: The role of institutions in China. *Journal of Economic Behavior & Organization* 94: 281-294.

Heede, R. 2014. Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. *Climatic Change* 122(1-2): 229-241.

Hertwich, E. G., T. Gibon, E. A. Bouman, A. Arvesen, S. Suh, G. A. Heath, J. D. Bergesen, A. Ramirez, M. I. Vega, and L. Shi. 2014. Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies. *Proceedings of the National Academy of Sciences*.

Hoekstra, A. Y. and T. O. Wiedmann. 2014. Humanity's unsustainable environmental footprint. *Science* 344(6188): 1114-1117.

Kagawa, S., S. Suh, K. Hubacek, T. Wiedmann, K. Nansai, and J. Minx. 2015. CO2 emission clusters within global supply chain networks: Implications for climate change mitigation. *Global Environmental Change.*

Kander, A., M. Jibron, D. D. Moran, and T. O. Wiedmann. 2015. National greenhouse-gas accounting for effective climate policy on international trade. *Nature Clim. Change* 5(5): 431-435.

Kanemoto, K., D. Moran, M. Lenzen, and A. Geschke. 2014. International trade undermines national emission reduction targets: New evidence from air pollution. *Global Environmental Change* 24(0): 52-59.

Kanemoto, K., M. Lenzen, G. P. Peters, D. D. Moran, and A. Geschke. 2012. Frameworks for Comparing Emissions Associated with Production, Consumption and International Trade. *Envionmental Science and Technology* 46: 172-179.

Lenzen, M. 2008. Life cycle energy and greenhouse gas emissions of nuclear energy: A review. *Energy Conversion and Management* 49(8): 2178-2199.

Lenzen, M. 2011. Aggregation versus disaggregation in input-output analysis of the environment. *Economic Systems Research* 23(1): 73-89.

Lenzen, M., J. Murray, F. Sack, and T. Wiedmann. 2007. Shared producer and consumer responsibility — Theory and practice. *Ecological Economics* 61(1): 27-42.

Lin, J., D. Pan, S. J. Davis, Q. Zhang, K. He, C. Wang, D. G. Streets, D. J. Wuebbles, and D. Guan. 2014. China's international trade and air pollution in the United States. *Proc Natl Acad Sci*.

Liu, Z., D. Guan, D. Crawford-Brown, Q. Zhang, K. He, and J. Liu. 2013. A low-carbon road map for China. *Nature* 500(7461): 143-145.

López, L.-A., G. Arce, and J. Zafrilla. 2014a. Financial Crisis, Virtual Carbon in Global Value Chains, and the Importance of Linkage Effects. The Spain–China Case. *Environmental Science & Technology* 48(1): 36-44.

López, L. A., G. Arce, and J. E. Zafrilla. 2013. Parcelling virtual carbon in the pollution haven hypothesis. *Energy Economics* 39(0): 177-186.

López, L. A., M. Á. Cadarso, J. E. Zafrilla, and G. Arce. 2014b. Assessing the implications on air pollution of an alternative control-based criterion. *Proceedings of the National Academy of Sciences*.

Marques, A., J. Rodrigues, M. Lenzen, and T. Domingos. 2012. Income-based environmental responsibility. *Ecological Economics* 84(0): 57-65.

O'Rourke, D. 2014. The science of sustainable supply chains. *Science* 344(6188): 1124-1127.

Pasinetti, L. 1973. The notion of vertical integration in economic analysis. *Metroeconomica. International Review of Economcis* 25(1): 1-29

Peters, G. and E. Hertwich. 2008. Post-Kyoto greenhouse gas inventories: production versus consumption. *Climatic Change* 86(1-2): 51-66.

Peters, G. P. 2008. From production-based to consumption-based national emission inventories. *Ecological Economics* 65(1): 13-23.

Peters, G. P., S. J. Davis, and R. M. Andrew. 2012. A synthesis of carbon in international trade. *Biogeosciences Discuss* 9(3): 3949-4023.

Sánchez-Choliz, J. and R. Duarte. 2005. CO_2 emissions embodied in international trade: evidence for Spain. *Energy Policy* 32(18): 1999 - 2005.

Skelton, A. 2013. EU corporate action as a driver for global emissions abatement: A structural analysis of EU international supply chain carbon dioxide emissions. *Global Environmental Change* 23(6): 1795-1806.

Skelton, A. 2014. Multinational Enterprises in Multi-Regional Input-Output Analysis. *22nd International Input-Output Conference, Lisbon, Portugal*.

Su, B. and B. W. Ang. 2010. Input–output analysis of CO2 emissions embodied in trade: The effects of spatial aggregation. *Ecological Economics* 70(1): 10-18.

Su, B. and B. W. Ang. 2013. Input–output analysis of CO2 emissions embodied in trade: Competitive versus non-competitive imports. *Energy Policy* 56(0): 83-87.

UNFCCC. 1992. United Nations Framework Convention on Climate Change. *United Nations*.

Weinzettel, J., K. Steen-Olsen, E. G. Hertwich, M. Borucke, and A. Galli. 2014. Ecological footprint of nations: Comparison of process analysis, and standard and hybrid multiregional input–output analysis. *Ecological Economics* 101(0): 115-126.

Wiedmann, T., M. Lenzen, K. Turner, and J. Barrett. 2007. Examining the global environmental impact of regional consumption activities — Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. *Ecological Economics* 61(1): 15-26.

Xia, Y., Y. Fan, and C. Yang. 2015. Assessing the impact of foreign content in China's exports on the carbon outsourcing hypothesis. *Applied Energy* 150(0): 296-307.

Zafrilla, J. E., M.-Á. Cadarso, F. Monsalve, and C. de la Rúa. 2014. How Carbon-Friendly Is Nuclear Energy? A Hybrid MRIO-LCA Model of a Spanish Facility. *Environmental Science & Technology*.