Responsibility and Trade Emission Balances: An Evaluation of Approaches

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Abstract:
This paper compares two concepts to evaluate the international responsibility of a country with respect to its emissions. Using a multi-regional input-output model, we show that the trade emission balance and the responsibility emission balance yield the same result. In practical work, however, a lack of data availability implies that the same technology assumption has been commonly adopted. In that case, also a third alternative exists, which simply evaluates the emissions embodied in the trade balance of the country. This third alternative yields the same results as the other two approaches at the aggregate level. At the level of individual products, however, the results are clearly different and it turns out that the third alternative answers a different question. That is, it is appropriate for measuring the emission content of the products that cross the border. In our empirical application, we consider Spain in 1995 and 2000, distinguishing nine different gases: CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, SO_2, NO_x, and NH_3.

Keywords:
International trade, Producer and consumer responsibility, Atmospheric pollutants, Multi-regional input-output model

J.E.L. classification codes: C67, F18, Q53.

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1. Introduction

International trade links the consumption in one country to emissions generated in other countries. As a consequence, the emissions actually generated in one country do not need to be the same as the emissions that are (directly and indirectly) necessary for its consumption. The debate about the implications of international trade on the environment, although not new, has gained much importance in the last decade due to the Kyoto protocol, which determines emission ceilings on six specified greenhouse gases (GHG) for each ratifier country (United Nations, 1997). These national targets, as well as the official data for monitoring countries' achievements, have been fixed on the basis of emissions generated by domestic production including emissions embodied in exports but not those embodied in imports. Such approach is particularly relevant to open economies and it has been suggested that international trade should be considered to establish equitable and feasible reduction targets (Munksgaard and Pedersen, 2001).

This situation leads to the question of how to evaluate the environmental responsibility of one country in global terms; that is, what would be the responsibility of one country regarding the rest of the world (RoW)? Traditionally, this aspect has been approached from two viewpoints. On the one hand, comparing the emissions embodied in exports with those embodied in imports; and on the other hand, confronting the producer and consumer responsibilities.

This paper aims at contributing theoretically and empirically to this issue by merging both approaches. We use an environmentally extended multi-regional input-output model to define and compare two concepts for the international (environmental) balances. These are, the trade emission balance (defined as the difference between the emissions embodied in exports and imports) and the responsibility emission balance (defined as the difference between the producer and consumer responsibility). Although both emission balances are derived from different approaches, we show that they are equivalent and thus yield the same result for the international responsibility of a country.

Due to a lack of data, many studies adopt the simplifying assumption that the domestic technological and the emission coefficients apply also abroad. For a small open country, a third alternative emission balance is frequently used: namely, the emissions corresponding to the trade balance (i.e. the net exports) of a country. This third alternative is attractive because it requires much less data. We show that it equals the other two emission balances at the aggregate level (i.e. measuring total emissions). However, the detailed results for the emission balance of individual products are entirely different. We will argue that the third alternative answers a different type of question and is appropriate for measuring the emission content of the products that cross the border. The original two alternatives are more appropriate for analyzing the responsibilities as emissions are attributed to products of final use.

For the empirical analysis, we have applied the model to the Spanish economy in 1995 and 2000. We compute the results for nine different gases: the six GHG regulated by the Kyoto protocol—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs)—and three other gases related to local environmental pressures—sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3).

The remainder of the paper is as follows. Section 2 provides the background for this study. In Section 3, we develop an environmentally extended multi-regional input-output model to define the trade emission balance and the responsibility emission balance and we will prove their equivalence. Also we will discuss the third alternative (i.e. emissions of net exports) and show the equality with the other two balances at the aggregate level. In Section 4, we analyze the results for Spain in 1995 and 2000. They clearly show that the former equivalence at the aggregate level does not hold at the detailed product level. Finally, conclusions are presented in Section 5.

2. Background

As shown the comprehensive surveys of Jayadevappa and Chhatre (2000) and Wiedmann *et al.* (2007), since the 1970s there has been a growing interest on the interactions between trade and environment. The first study in analyzing the emissions contained in the international trade of the United States (U.S.) was Walter (1973). However, in the last years there has been an increase of studies that compare the emissions associated with exports and imports for different countries, such as Germany and the United Kingdom (U.K.) (Proops *et al.*, 1993), Japan (Kondo *et al.*, 1998), Denmark (Munksgaard and Perdersen, 2001), Brazil (Machado *et al.*, 2001; Tolmasquim and Machado, 2003), Spain (Sánchez-Chóliz and Duarte, 2004), Italy (Mongelli *et al.*, 2006), India (Mukhopadhyay and Chakrabory, 2005; Dietzenbacher and Mukhopadhyay, 2007), and Turkey (Tunç *et al.*, 2007). Antweiler (1996) calculated an index of pollution terms of trade for 164 different countries.

Although there are methodological differences, all these studies have a common feature, i.e. they assume that the RoW has the same technology as the country analyzed. This assumption is frequently adopted due to the lack of data concerning the 'global' technology of the RoW. However, improvements in data availability and quality have made possible, in some cases, to take different technologies between regions into account. Thus, bilateral trade studies have been carried out between Japan and Canada (Hayami and Nakamura, 2002), Japan and South Korea (Rhee and Chung, 2006), Japan and the U.S. (Ackerman *et al.*, 2007), and Canada and the U.S. (Norman *et al.* 2007). Other studies have considered more regions such as Wyckoff and Roop (1994) who estimated the embodied emissions in imports of six OECD countries (Canada, France, Germany, Japan, the U.K., and the U.S.). Ahmad and Wyckoff (2003) enlarged this study estimating the emissions embodied in international trade of goods of 24 OECD countries. Lenzen *et al.* (2004) calculated the trade balance taking into account five regions (Denmark, Germany, Sweden, Norway and the RoW); Nijdam *et al.* (2005) analyzed the impacts of Dutch household consumption considering the Netherlands and three different world regions; Peters and Hertwich (2006a, 2006b) analyzed the environmental impacts of Norway's final demand aggregating all its trading partners into seven regions; and Weber and Matthews (2007) analyzed the environmental effects of changes to the structure and volume of U.S. trade with Canada, China, Mexico, Japan, Germany, the U.K. and Korea. The largest multi-regional studies consider 87 countries: Peters and Hertwich (2008a) analyzed CO_2 emissions embodied in international trade; Wilting and Vringer (2009) also included CH_4, N_2O and land use; Hertwich and Peters (2009) compared carbon footprints; and Andrew *et al.* (2009) quantified errors induced by applying different assumptions. However, the principal drawback to this approach is the difficulty of getting the necessary and detailed data on interregional transactions; and when this information is available it should be cautiously used because of the lack of consistency and accuracy of some databases (Peters and Hertwich, 2008a). Moreover, even in these multi-regional studies it is necessary to make some assumption about the technology of the RoW when it is considered as a region in the model. Nevertheless, all these studies are a sign of the importance of considering different technologies when estimating the emissions embodied in trade.

On the other hand, the international environmental responsibility of a country can also be defined from a different perspective. Since the place where the production of goods and services takes place does not need to be the same as the place where these products are 'consumed', we can define the responsibility of a country from two sides: the producer or the 'consumer' standpoint[1] (Proops *et al.*, 1993; Steenge, 1999; Munksgaard and Pedersen, 2001). The former establishes that any country is responsible for the emissions within the country associated with its domestic production regardless where it is going to be 'consumed'. Whereas the latter determines the country's responsibility depending on its 'consumption', i.e. a country is responsible for emissions generated globally in order to satisfy its domestic final demand regardless where it has been produced. This second perspective coincides with the philosophy of the ecological footprint (Rees, 1992; Rees and Wackernagel, 1994; Wackernagel and Rees, 1996), which reflects total (real and virtual) land that a country would need to absorb the impact of its residents on the earth. This concept can be appropriately calculated by applying multi-regional input-output models (Bicknell *et al.*, 1998; Wiedmann *et al.*, 2006; Turner *et al.*, 2007).

The distinction between producer and 'consumer' responsibility has also generated other interesting contributions closely related to our study, but not investigated in this article. On the one hand, the methodological debate about sharing responsibility that deals with the question of how to assign the environmental responsibility (Gallego and Lenzen, 2005; Rodrigues *et al.*, 2006; Lenzen *et al.*,

[1] This is the terminology commonly used in the literature. However, the term "consumer responsibility" refers to emissions derived from all domestic final demand and not exclusively from household consumption. A more appropriate term, therefore, would be "final user responsibility". In this paper we will use both and add single quotation marks for 'consumer' or 'consumption'.

2007; Rodrigues and Domingos, 2008); and on the other hand, the analysis of the appropriateness of production-based versus consumption-based national emission inventories (Peters and Hertwich, 2008b; Peters, 2008).

3. Methodology

3.1. The Multi-regional Input-Output Framework

We consider a world economy consisting of two regions (*r*, *s* = 1, 2) that may differ in production technology and/or pollution patterns. Each region is composed of *n* sectors, which produce one product that might be used by other sectors as intermediate input (either at home or abroad) or consumed or invested (at home or abroad) as final product by final user categories such as households and the government. The model is given by $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$, or in its partitioned form as[2]

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} + \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{1}$$

with $\mathbf{A}^{11}$ and $\mathbf{A}^{22}$ the matrices of domestic input coefficients, and $\mathbf{A}^{12}$ and $\mathbf{A}^{21}$ the coefficient matrices for the imported inputs. Similarly, $\mathbf{y}^{11}$ and $\mathbf{y}^{22}$ represent the domestic final demands, and $\mathbf{y}^{12}$ and $\mathbf{y}^{21}$ give the imports by final users (i.e. households and the government). The gross outputs are given by $\mathbf{x}^1$ and $\mathbf{x}^2$. The solution of $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$ is given by $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\mathbf{y}$, where $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ indicates the Leontief inverse. In partitioned form, this reads as follows

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} \\ \mathbf{L}^{21} & \mathbf{L}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{2}$$

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

In order to estimate emissions associated with the production in each region, we define the matrix of atmospheric emission coefficients $\mathbf{W}^r$, whose element w_{kj}^r indicates the domestic emission of pollutant *k* per unit of industry *j*'s output in region *r*. The emissions (or pollution) generated in each region are given by

$$\begin{pmatrix} \mathbf{p}^1 \\ \mathbf{p}^2 \end{pmatrix} = \begin{pmatrix} \mathbf{W}^1\mathbf{x}^1 \\ \mathbf{W}^2\mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{W}^1\mathbf{L}^{11} & \mathbf{W}^1\mathbf{L}^{12} \\ \mathbf{W}^2\mathbf{L}^{21} & \mathbf{W}^2\mathbf{L}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix}$$
$$= \begin{bmatrix} \mathbf{P}^{11} & \mathbf{P}^{12} \\ \mathbf{P}^{21} & \mathbf{P}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{3}$$

Note that element p_{kj}^{rs} of matrix $\mathbf{P}^{rs}$ gives the total amount of (extra) emissions of pollutant *k* in region *r*, due to the delivery of one (extra) unit of product *j* from region *s* to its final users (either at home or abroad).

3.2. Trade and Responsibility Emission Balances

Analyzing emissions embodied in international trade requires the comparison of the emissions embodied in exports with the emissions embodied in imports. For region 1, we have

$$em\ exp\ 1 = \mathbf{P}^{11}\mathbf{y}^{12} + \mathbf{P}^{21}\mathbf{y}^{12} + \mathbf{P}^{12}(\mathbf{y}^{21} + \mathbf{y}^{22}) \tag{4}$$

The first component gives the (domestic and foreign) emissions embodied in the exports $\mathbf{y}^{12}$ of region 1 to foreign final users. The second component gives the domestic emissions embodied in the exports of the inputs that enter the production process in region 2 for satisfying its final users (both domestic and foreign). In the same fashion, we have for the emissions embodied in region 1's imports

$$em\ imp\ 1 = \mathbf{P}^{22}\mathbf{y}^{21} + \mathbf{P}^{12}\mathbf{y}^{21} + \mathbf{P}^{21}(\mathbf{y}^{11} + \mathbf{y}^{12}) \tag{5}$$

The trade emission balance for region 1 (i.e. $\mathbf{teb}^1$) is defined as the difference between the emissions embodied in exports and those embodied in imports. That is

$$\mathbf{teb}^1 = \mathbf{P}^{11}\mathbf{y}^{12} + \mathbf{P}^{12}\mathbf{y}^{22} - \mathbf{P}^{22}\mathbf{y}^{21} - \mathbf{P}^{21}\mathbf{y}^{11} \quad (6)$$

The trade emission balance for region 2 may be obtained in the same way. In this two-region case, we then have $\mathbf{teb}^2 = -\mathbf{teb}^1$, or $\mathbf{teb}^1 + \mathbf{teb}^2 = 0$. Note that the term $\mathbf{P}^{21}\mathbf{y}^{12} + \mathbf{P}^{12}\mathbf{y}^{21}$ is both in (4) and in (5). It reflects emissions that are first imported and then exported again. In the balance in (6) they cancel each other out.

The international responsibility of a region is defined from a different perspective. That is, by comparing the emissions produced inside the region with the emissions required by its domestic final users. The producer's responsibility in region 1 covers all emissions generated by the region's production, i.e. $\mathbf{W}^1\mathbf{x}^1$. From (3) it follows

$$em\ prod\ 1 = \mathbf{P}^{11}(\mathbf{y}^{11} + \mathbf{y}^{12}) + \mathbf{P}^{12}(\mathbf{y}^{21} + \mathbf{y}^{22}) \quad (7)$$

However, from the viewpoint of the final users in region 1, the region is responsible for all emissions that are caused by their 'consumption' (i.e. $\mathbf{y}^{11}$ and $\mathbf{y}^{21}$), no matter where the emissions have been generated. This corresponds to the region's ecological footprint.[3] This yields

$$em\ finus\ 1 = (\mathbf{P}^{11} + \mathbf{P}^{21})\mathbf{y}^{11} + (\mathbf{P}^{12} + \mathbf{P}^{22})\mathbf{y}^{21} \quad (8)$$

The responsibility emission balance for region 1 (i.e. $\mathbf{reb}^1$) is defined as the difference between the emissions due to the producer responsibility and the 'consumer' responsibility. That is, equation (7) minus equation (8). It is readily seen that this yields equation (6), which proves that $\mathbf{teb}^1 = \mathbf{reb}^1$.

3 It should be mentioned that both for calculating the territorial emissions and the footprints, the emissions corresponding to the actual consumption of goods and services should be added to the producer and final user responsibility, respectively. Because this paper focuses on their difference, we have not taken these direct consumption emissions into account at all.

If the balances have a positive sign it implies that the emissions embodied in exports are higher than those embodied in imports, i.e. the region is a “net importer” of emissions or, alternatively, the producer responsibility is larger than the ‘consumer’ responsibility.[4] Since official statistics reflect territorial data (i.e. emissions generated by domestic production) this region would actually be less responsible for the environmental pollution than is reported. In terms of ecological footprints, a positive balance would reflect an ecological creditor region, which has enough ecological resources within its own territory and, hence, it would be ‘ceding’ land to the other region.

The analysis in this section can be readily extended to the multi-region case and the results remain the same. The only difficulty is that the equality $\mathbf{teb}^2 = -\mathbf{teb}^1$ for the two-region case does not hold for the multi-region case. Instead, we have ‘consistency’ of the balances in the sense that $\mathbf{teb}^1 + \mathbf{teb}^2 + ... + \mathbf{teb}^m = 0$.

The intuition behind the equality of the responsibility and the trade emission balance has been widely discussed at the aggregate level in a single country setting and has led to simple graphical representations (see e.g. Weidema *et al.*, 2006). Whether it holds at a sectoral level within a multi-regional setting depends on the definitions of emissions in exports, emissions in imports, producer responsibility, and ‘consumer’ responsibility. In this paper, we have started from plausible definitions (4), (5), (7), and (8), and proved the equivalence. In contrast, e.g. Peters and Hertwich (2008a), did the opposite and imposed the equality $\mathbf{teb}^r = \mathbf{reb}^r$ to define ‘consumer’ responsibility in a single country case with multiple countries, which corresponds to setting $\mathbf{A}^{12} = \mathbf{A}^{21} = 0$ in our equation (1).

3.3. Special Case: A Small Country Using the Same Technology

The special case of a small country is discussed in this subsection. Using the model of the previous subsection, the country is region 1 and the RoW is region 2. Although the exports of the country are non-zero, for a small country they will typically be

4 A positive trade and/or responsibility balance can also be interpreted as an environmental opportunity cost.

negligible when compared to the RoW's outputs. Therefore it seems plausible to assume that $\mathbf{A}^{12} = 0$.

The second assumption that we will make is quite common in the literature. Although technology will differ across countries, actual data for the RoW are typically lacking. Therefore it is assumed that the production technology and the emission intensities are the same for the country and the RoW. Note that the technology is given by the structure of the inputs, no matter whether domestically produced or imported. That is, assuming the same technology implies $\mathbf{A}^{11} + \mathbf{A}^{21} = \mathbf{A}^{22} + \mathbf{A}^{12}$ (together with the assumption that $\mathbf{A}^{12} = 0$, this yields $\mathbf{A}^{11} + \mathbf{A}^{21} = \mathbf{A}^{22}$) and assuming the same emission intensities implies $\mathbf{W}^{1} = \mathbf{W}^{2}$.

We can now simplify the notation. Writing $\mathbf{A}^{11} = \mathbf{A}$ for the domestic input coefficients, $\mathbf{A}^{21} = \mathbf{M}$ for the import coefficients, and writing $\mathbf{A} + \mathbf{M}$ for the technical input matrix (that holds for both countries), equation (1) becomes

$$\begin{pmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \end{pmatrix} = \begin{bmatrix} \mathbf{A} & 0 \\ \mathbf{M} & \mathbf{A}+\mathbf{M} \end{bmatrix} \begin{pmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \end{pmatrix} + \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{9}$$

Instead of equation (3) we now have

$$\begin{pmatrix} \mathbf{p}^{1} \\ \mathbf{p}^{2} \end{pmatrix} = \begin{bmatrix} \mathbf{W}(\mathbf{I}-\mathbf{A})^{-1} & 0 \\ \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1} & \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{10}$$

The emission balance (no matter whether trade or responsibility) in (6) now becomes

$$\begin{aligned} \mathbf{eb}^{1} = {} & \mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{12} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{y}^{21} \\ & - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{11} \end{aligned} \tag{11}$$

Usually, a much simpler expression is used when the assumption of the same technology is adopted. That is, calculating the emissions corresponding to the trade balance (i.e. exports minus imports). So, the alternative expression is given by

$$\overline{\mathbf{eb}}^1 = \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}(\mathbf{exp}^1 - \mathbf{imp}^1) \tag{12}$$

where $\mathbf{exp}^1 = \mathbf{y}^{12}$ gives the vector of exports of country 1 and $\mathbf{imp}^1$ the vector of total imports. Note that it follows from (9) that $\mathbf{imp}^1 = \mathbf{Mx}^1 + \mathbf{y}^{21} = \mathbf{M}(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{y}^{11} + \mathbf{y}^{12}) + \mathbf{y}^{21}$. The alternative in equation (12) has one major advantage in terms of data requirements. Observe that the application of (11) requires that the input-output data are such that the domestically produced inputs are separated from the imported inputs. Such data are not always available and for many countries only the sum of the two matrices (i.e. the technical input matrix $\mathbf{A}+\mathbf{M}$) is available. In addition, equation (11) requires the vectors of imports and exports separately, while equation (12) only requires the vector of net exports. Appendix A shows that the two expressions in (11) and (12) are the same, so that also in the case where only a technical input matrix is available we arrive at the same answer.

However, this equivalence does not hold when analyzing emission balances at the level of product detail. Let $\hat{\mathbf{y}}^{12}$, $\hat{\mathbf{y}}^{21}$, $\hat{\mathbf{y}}^{11}$, $\mathbf{e\hat{x}p}^1$, and $\mathbf{i\hat{m}p}^1$ be diagonal matrices. The emission balances at product level as derived from expression (11) is

$$\begin{aligned}\mathbf{EB}^1 = {} & \mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{y}}^{12} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\hat{\mathbf{y}}^{21} \\ & - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{y}}^{11}\end{aligned} \tag{13}$$

The element eb_{kj}^1 gives the emission balance for region 1 of pollutant *k* corresponding to the exports of product *j*, the imports of product *j* by final users, and the imports necessary for producing the domestic 'consumption' of product *j*.

Equation (12) now becomes

$$\overline{\mathbf{EB}}^1 = \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}(\mathbf{e\hat{x}p}^1 - \mathbf{i\hat{m}p}^1) \tag{14}$$

The element $\overline{eb}_{kj}^1$ gives the total emissions of pollutant *k* corresponding to region 1's net exports of product *j*. The empirical results in the next section show that the findings from equations (13) and (14) are not the same, and we will discuss the differences.

4. Empirical Results

This section presents the empirical results for the models presented above. The basic data sources of this paper are the 1995 and 2000 Spanish NAMEA for air emissions (INE 2005, 2006). Appendix B discusses the data set and the assumptions and procedures adopted in this paper.

4.1. Aggregate Results

Tables 1 and 2 present the aggregate emission balances for Spain in 1995 and 2000. Table 1 exhibits the Spanish trade emission balance for both years, showing that the emissions embodied in imports are higher than the emissions embodied in exports. Spain thus has a negative trade emission balance for all gases in both years, with the exception of NH_3 in 2000. Consequently, Spain would have been 'exporting' pollution if the RoW had produced commodities using the same technology as Spain.[5]

INSERT TABLE 1

Table 2 reflects the international responsibility of Spain by comparing the emissions produced in Spain with those required by its domestic final demand. The producer responsibility is lower than the 'consumer' responsibility for almost all gases in both years. The differences for 1995 and 2000 show that the responsibility emission balances for Spain are exactly the same—of course—as in Table 1.

It should be emphasized that most official statistics, including IPCC inventories and NAMEAs, report data on territorial emissions from the producer

[5] Although it is a restrictive assumption, it is by no means implausible in the case of Spain. Andrew *et al.* (2009, Table 1) showed that applying this assumption for Spain results in a 1% error in the carbon footprint, when compared to a full multi-regional input-output model.

perspective.[6] Also policy measures such as the Kyoto Protocol are based on this viewpoint. The results in Tables 1 and 2 indicate that official reports seriously underestimate the responsibility of Spanish domestic final demand. 'Consumer' responsibility for the GHG (in CO_2 equivalent) is 9% (resp. 15%) larger than producer responsibility in 1995 (resp. 2000), showing that from the ecological footprint viewpoint Spain is a debtor country that is 'usurping' land.

INSERT TABLE 2

Both emission balances can be interpreted as an indicator for the international environmental responsibility of a country. The implications of a negative emission balance, either trade or responsibility, may vary depending on the kind of pollutant considered. In the case of local and regional gases, such as SO_2, NO_x, and NH_3, it means that Spain shifts environmental costs to other countries. For global pollutants, such as the GHG, it means that the responsibility of the country is greater than it appears from official reports.

Considering the changes in environmental responsibility over time, it follows from the last column in Table 2 that the international responsibility of Spain increased considerably between 1995 and 2000. Note that a positive (negative) percentage change indicates an increase (decrease) of the deficit on the balance. It appears that the deficit has roughly doubled for the synthetic GHG and for two of the three gases related to energy products, i.e. CO_2 and NO_x. For SO_2 the increase was much more moderate. In contrast, the evolution of the international responsibility for the gases connected with agricultural and food activities, i.e. CH_4, N_2O, and NH_3, was just the opposite; their deficits have decreased and Spain has even become an 'importer' of pollution in terms of NH_3 emissions. The different behavior between both groups of gases mainly reflects changes in final demand structure during this period (Roca and Serrano, 2007). With respect to climate change, also the deficit for the total amount of GHG (measured in CO_2 equivalent) has almost doubled. The

[6] IPCC inventories and NAMEAs use different territorial concepts though. The IPCC data register all emissions (including those generated or absorbed by nature itself) within the geographic territory; NAMEAs cover emissions generated by the residents within an economic territory.

producer responsibility has increased by 17% between 1995 and 2000, whereas the ‘consumer’ responsibility has increased by no less than 24%.

4.2. Detailed Results at Product Level

In Section 3.3 we showed that under the assumption of the same technology, the emission balance (no matter whether trade or responsibility) at the aggregate level (i.e. for a country) can be calculated by applying either expression (11) or the simpler shortcut expression (12), which was used e.g. in Machado *et al.* (2001) or Mongelli *et al.* (2006). However, when we calculate the emission balance at the detailed level of products, the counterpart expressions (13) and (14) lead to different outcomes. The results are given in Table 3 for GHG.[7]

The totals in the bottom row of Table 3 coincide with the emission balances for GHG in Tables 1 and 2. At the aggregate level, expressions (13) and (14) yield the same result. For separate products, however, the emission balances differ largely. In fact, each expression answers a different research question. The general expression (13) gives the difference between producer and ‘consumer’ responsibility, whereas the shortcut expression (14) evaluates the emissions embodied in the products that cross the border.

INSERT TABLE 3

For example, for ‘Pulp, paper and paper products’ (sector 13, for short: paper), the emission balance in 1995 for GHG is roughly 0.6 million tonnes of CO_2 equivalent. The difference between producer and ‘consumer’ responsibility captures: the Spanish emissions involved in producing the exports of Spanish paper to foreign ‘consumers’; minus the foreign emissions involved in producing the imports of foreign paper by Spanish ‘consumers’; minus the foreign emissions involved in producing the imported inputs that are required in Spain to produce paper for Spanish ‘consumers’. From the first two columns in Table 3, it follows that Spain imported almost twice as much paper than it exported (for 2706 and 1367 million euros,

[7] Detailed information for separate gases (CO_2, CH_4, N_2O, synthetic gases, SO_2, NO_x, and NH_3) is available upon request from the authors.

respectively) in 1995. However, what matters in the emission balance in equation (13) is the final use or ‘consumption’ of paper. In the input-output framework the ultimate goal of all production is ‘consumption’. Emissions are therefore attributed to or embodied in ‘consumption’. In the case of paper, for example, the exports of Spanish paper to foreign ‘consumers’ equal 1367 million euros, whereas the Spanish imports of paper by ‘consumers’ amount only to 119 million euros. This means for instance that a very large part of the imports of paper (i.e. 2587 million euros) is as an intermediate input for the production of (mainly) other goods than paper. The foreign emissions involved in producing this imported paper will be accounted for in the ‘consumption’ of these other goods.

The shortcut expression (14) has a different focus. The vector $\mathbf{imp}^1$ gives all the imports into Spain. This includes the foreign paper that goes to Spanish ‘consumers’, but also the imports of foreign paper by Spanish producers to make other goods (for ‘consumption’ in Spain or abroad). In this last case, expression (14) does not attribute emissions to the product of final use, as was the case in (13). Instead, expression (14) reflects the viewpoint of measuring trade at the border, where customs simply measure the goods that cross the border, no matter whether they are for final use or for further production. For example, take the exports of Spanish paper to foreign ‘consumers’, for which Spain imports foreign wood products as inputs. In expression (13), only the Spanish emissions for paper production are taken into account, not the foreign emissions. These foreign emissions (part of which stem from the wood products that go into Spanish paper) have been imported and then exported again, and thus cancel out. In expression (14), all emissions (Spanish as well as foreign emissions involved in producing inputs such as wood products) are included the paper exports. The emissions involved in the foreign production of wood products that are imported by Spain are *not* listed (i.e. subtracted) under ‘paper’, but under ‘wood products’.

The shortcut expression (14) measures all trade as if it were a final product. Consequently, as long as the net exports of a product are positive (negative) the emission balance will show a positive (negative) outcome. For example, in the case of paper we find an emission balance of -1.3 million tonnes of CO_2 equivalent (which contrasts the +0.6 million tonnes when expression (13) is used) in 1995. Note that summing over the products yields the same result for (13) and (14). This implies that at the product level, the emissions have been redistributed. In expression (13) the emissions are attributed to the product of final use, whereas in expression (14) the emissions are attributed to the products that actually cross the border.

Sector 44 ‘Health and social work’ illustrates another consequence of the difference between the two expressions. The two first columns in Table 3 indicate that Spain neither exported nor imported any ‘health services’ in 1995. The emission balance thus equals zero when the shortcut expression (14) is used, because no ‘health services’ cross the border. Using the general expression (13), it follows from Table 3 that the emission balance was negative for all gases. The reason is that this sector used some inputs produced abroad such as chemical products (sector 16) or medical and precision instruments (sector 25). The corresponding foreign emissions are attributed to the Spanish ‘consumption’ of health services.

Summarizing the discussion about the contents of and the difference between the general expression (13) and the shortcut expression (14), the first seems to be more appropriate for measuring responsibilities, which rely heavily on the principle of embodied emissions. The shortcut expression comes closer to measuring the emission content of the products that cross the border.

In order to further analyze the difference between expression (13) and (14), we derive the most important players in terms of the emission balance. Table 4 shows the products that contribute the most (in either direction) to the difference between the two responsibilities, which might be relevant also from a policy perspective.

INSERT TABLE 4

The lower part of Table 4 (for the shortcut expression) is relatively simple to interpret. It corresponds to the balance of the emissions generated for the products that cross the border. If the exports are much larger (smaller) than the imports and if producing the good or service generates a large amount of emissions, it will be a key product with a positive (negative) balance. The upper part of the table (for the general expression) is less straightforward to interpret. Roughly speaking, however, we find that products that are in the initial stages of the production process have a positive balance. The reason is that these products require relatively few imported inputs. In contrast, products that are in the final stages of the production process typically rely heavily on intermediate inputs. A part of them will be imported which often leads to a negative balance.

Note that in some cases the key products coincide. On the one hand, this happens when Spain is a net exporter of a certain ‘primary’ product, which results in a positive balance. In 1995, this occurs for ‘Other non-metallic mineral products’ (sector 18) and ‘Water transport’ (sector 36). On the other hand, negative balances are found when Spain is a net importer of ‘final’ products, such as ‘Food products, beverages, and tobacco’ (sector 8) and ‘Machinery and equipment’ (sector 21).

At least as interesting are the key products for which the two expressions yield opposite outcomes. In 1995, this is observed for two products, i.e. ‘Basic metals’ (sector 19) and ‘Chemicals and chemical products’ (sector 16). In both cases, the imports are substantially larger than the exports, which explains why they show a negative balance for the shortcut expression (14). From the perspective of expression (13), however, basic metals and chemicals are typical ‘primary’ products that are used by many other industries as an intermediate input. The Spanish imports of these products (and their foreign emissions) will therefore be taken into account by (i.e. attributed to the ‘consumption’ of) other products and not by basic metals or chemicals.

The results for 2000 show that the cases where key products have a coinciding balance decreased, whereas those with opposite balances increased. We also find a key product (‘Wholesale and retail trade’, sector 33) for which the exports exceed the imports (and thus a positive balance in the lower part of the table), whereas expression (13) shows a negative balance (in the upper part of the table). Although this sector is one of the largest exporters, its services include a relatively small amount of Spanish emissions, whereas its production relies heavily on imported intermediate inputs (and their corresponding emissions).[8] Also it is interesting to observe that ‘Air transport’ (sector 37) has taken over the role of

[8] It should be mentioned that a quarter of the export’s value of sector 33 corresponds to trade margins. The rest includes sales of motor vehicles and related accessories, and the usual manipulations involved in wholesale (such as assembling, sorting, packing, bottling).

‘Water transport’ (sector 36) and that the imports of ‘Crude petroleum and natural gas’ (sector 5) have almost tripled (with an obvious effect when using the shortcut expression) between 1995 and 2000.

5. Conclusions

On the basis of a multi-regional input-output model we defined and compared two concepts to evaluate the international responsibility of emissions generated by one country. We defined the trade emission balance as the difference between the emissions embodied in a country’s exports and imports; and the responsibility emission balance as the difference between the responsibility of one country as a producer and its responsibility as a ‘consumer’. Both emission balances were shown to be equivalent in the sense that they yield the same result. So, a negative (positive) balance would indicate that the country is ‘exporting’ (‘importing’) pollution and it would be more (less) responsible. The implications of these results may vary depending on the kind of pollutant considered: when analyzing GHG, the country’s responsibility on global environmental pressures would be greater than the official statistics report; when analyzing local gases, the country would be displacing environmental costs to other territories.

Although it has been widely recognized in the last decade that trade in emissions can be studied properly only if multi-regional input-output tables are used, such tables are rare.[9] Therefore, several studies have applied the same technology assumption (both in terms of production and emissions). We showed that—under this assumption—the two emission balances above are equivalent to a shortcut alternative. This third approach evaluates the emissions corresponding to the trade balance of the country and has a major advantage in terms of data requirements. The equivalence,

[9] An early exception is the series of tables for a set of European countries (in current and constant prices, for the years 1970, 1975, 1980, and 1985) that can be downloaded at http://www.regroningen.nl/irios_tables.shtml. Recently, however, several projects have started that focus on the construction of multi-country input-output tables. For instance, the EU-funded project, EXIOPOL, aims at constructing a multi-country for 43 countries with detailed information for environmental aspects (see http://www.feem-project.net/exiopol/, Tukker *et al.*, 2009). Another EU-funded project, WIOD, aims at constructing a time series of annual inter-country input-output tables (in current and constant prices) for 40 countries, including socio-economic and environmental satellite accounts (see http://www.wiod.org).

however, applies only at the aggregate level where responsibilities are evaluated for an entire country. The equivalence does not hold at the level of individual products and provides a true alternative. The first two types of emission balance are in particular appropriate for evaluating responsibilities at the product level, because these approaches attribute emissions to the ‘consumption’ of products. The alternative approach (which gives the emission of the trade balance) is more appropriate for evaluating the emissions that are embodied in the products that cross the border.

In our empirical application, we have calculated the emission balances for the Spanish economy in 1995 and 2000, for nine different gases: the six GHG (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three local gases (SO_2, NO_x, and NH_3). The results indicate that Spain benefited—in environmental terms—from international trade, because the emissions would have been higher if all the products required by the Spanish final demand had been produced inside the country. Thus, Spain has been a ‘net exporter’ of emissions for all the nine gases considered in both years (with the exception of NH_3 in 2000). However, these results have to be interpreted carefully because of the same technology assumption. Factually, these are the emissions avoided by Spain because it purchases some products abroad.

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Appendix A. Equivalence of expressions for the emission balances.

Our starting point is equation (13)

$$\mathbf{eb}^1 = \mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{12} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{y}^{21} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{11}$$

Using the expression for the imports vector $\mathbf{imp}^1 = \mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}(\mathbf{y}^{11}+\mathbf{y}^{12})+\mathbf{y}^{21}$ gives that $\mathbf{y}^{21} = \mathbf{imp}^1 - \mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}(\mathbf{y}^{11}+\mathbf{y}^{12})$. Substituting this into the expression for the emission balance yields

$$\begin{aligned}\mathbf{eb}^1 &= \mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{12} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}[\mathbf{imp}^1 - \mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}(\mathbf{y}^{11}+\mathbf{y}^{12})] \\ &\quad - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}^{11} \\ &= [\mathbf{W}(\mathbf{I}-\mathbf{A})^{-1} + \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1}]\mathbf{y}^{12} - \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{imp}^1\end{aligned}$$

Next consider the sum of the two matrices in the bracketed term

$$\begin{aligned}&\mathbf{W}(\mathbf{I}-\mathbf{A})^{-1} + \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A})^{-1} \\ &= \mathbf{W}[\mathbf{I} + (\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\mathbf{M}](\mathbf{I}-\mathbf{A})^{-1} \\ &= \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}[(\mathbf{I}-\mathbf{A}-\mathbf{M})+\mathbf{M}](\mathbf{I}-\mathbf{A})^{-1} = \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}\end{aligned}$$

This yields $\mathbf{eb}^1 = \mathbf{W}(\mathbf{I}-\mathbf{A}-\mathbf{M})^{-1}(\mathbf{y}^{12} - \mathbf{imp}^1)$ and using $\mathbf{y}^{12} = \mathbf{exp}^1$ gives the expression in equation (14).

Appendix B. Spanish data and data preparation.

The Spanish NAMEA for air emissions is organized according to the supply and use table structure covering 110 CPA products, 72 NACE sectors plus a fictitious sector 'Financial Intermediation Services Indirectly Measured', and 7 categories of final uses. The Spanish use table offers information about total, domestic, and imported inputs of each sector. Further, the environmental accounts report direct emissions— in physical units— produced by 46 NACE sectors and by households.

Following the NAMEA principles air emissions related to incineration and decomposition of waste in landfills (mainly CO_2 and CH_4) are placed under NACE 90 'Sewage and refuse disposal services'. However, this sector is aggregated jointly with NACE 91, 92 and 93, which include cultural and sporting services, for example. Due to the nature of these four sectors, one can logically infer that most CH_4 emissions and also a smaller amount of CO_2 emissions will be generated almost exclusively by NACE 90; however, this information remains hidden because of the above aggregation. Following Keuning *et al.* (1999) we have assumed that all CH_4 emissions generated by this aggregate (of the four original sectors) correspond to NACE 90 and we have reallocated them to a new category called 'other sources'.

Taking this into account, we have estimated a 46x46 environmentally extended symmetrical input-output table according to the technology industry hypothesis. From this input-output table, we have estimated the domestic and imported coefficient matrices **A** and **M**, and the emission coefficient matrix **W**.

Finally, the synthetic GHG (SF_6, HFCs, and PFCs) and the six GHG have been aggregated in accordance with the global warming potential (GWP100) of each gas as established by the IPCC (1997). These conversion factors are: 1 for CO_2, 21 for CH_4, 310 for N_2O, and 23,900 for SF_6. For the group of HFCs and PFCs these values oscillate between 140-11,700 and 6,500-9,200, respectively. We have calculated a GWP100 for HFCs and PFCs groups based on the average weight of each group obtaining a result of 6,813 for HFCs and 6,729 for PFCs.

Table 1: Trade emission balances

	Emissions embodied in exports (1)		Emissions embodied in imports (2)		Trade emission balance (3)=(1)-(2)	
	1995	2000	1995	2000	1995	2000
CO_2	75443	120623	93663	160795	-18220	-40171
CH_4	374	548	475	591	-100	-43
N_2O	25	36	30	40	-6	-4
Synthetic GHG*	2722	5342	3737	7328	-1015	-1986
Total CO_2 equivalent	**93661**	**148702**	**116736**	**192860**	**-23075**	**-44158**
SO_2	600	658	723	805	-123	-147
NO_x	369	591	484	831	-115	-239
NH_3	99	157	115	150	-16	7

Units: thousand tonnes and %. Source: own elaboration from the 1995 and 2000 Spanish NAMEA.
* Synthetic GHG give the total of SF_6, HFCs and PFCs emissions, measured in CO_2 equivalent units.

Table 2: Responsibility emission balances

	Producer responsibility (1)		'Consumer' responsibility (2)		Responsibility emission balance (3)=(1)-(2)		Change of emission balance (%)
	1995	2000	1995	2000	1995	2000	
CO_2	203704	238632	221924	278803	-18220	-40171	120
CH_4	1112	1251	1212	1295	-100	-43	-57
N_2O	68	79	74	83	-6	-4	-37
Synthetic GHG*	3585	6235	4600	8221	-1015	-1986	96
Total CO_2 equivalent	**251738**	**295691**	**274813**	**339850**	**-23075**	**-44158**	**91**
SO_2	1760	1500	1883	1647	-123	-147	20
NO_x	1051	1141	1166	1381	-115	-239	109
NH_3	304	384	320	377	-16	7	-141

Units: thousand tonnes and %. Source: own elaboration from the 1995 and 2000 Spanish NAMEA.
* Synthetic GHG give the total of SF_6, HFCs and PFCs emissions, measured in CO_2 equivalent units.

Table 3: Emission balances for GHG by product, according to expressions (13) and (14)

		1995				2000			
		Total exports	**Total imports**	**(13)**	**(14)**	**Total exports**	**Total imports**	**(13)**	**(14)**
S1	Agriculture, hunting, and related services activities	4921	4711	6295085	449821	7027	4878	9707910	4657630
S2	Forestry, logging, and related services activities	63	198	40702	-107247	155	499	89672	-305652
S3	Fishing	129	663	-968140	-1247042	320	765	-989353	-930410
S4	Mining of coal and lignite; extraction of peat	0	514	-3651	-733058	1	876	-260	-1184077
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	3	5408	11902	-9359916	3	15513	-229774	-25437683
S6	Mining of metal ores	55	654	47206	-584017	99	1152	110562	-1327360
S7	Other mining and quarrying	255	303	225683	-50854	504	527	291881	-18345
S8	Manufacture of food products, beverages, and tobacco	5181	7493	-8631841	-3194084	9219	10843	-8444325	-2041786
S9	Manufacture of textile	1717	2068	-378375	-367803	2919	3694	-384670	-692610
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	826	1745	-2066455	-614372	2000	3773	-2704814	-1056587
S11	Tanning and dressing of leather; manufacture of luggage, and footwear	1550	889	-251275	451691	2227	1741	-456319	279290
S12	Manufacture of wood and of products of wood and cork, except furniture	481	876	136304	-259845	931	1811	206905	-550642
S13	Manufacture of pulp, paper, and paper products	1367	2706	579199	-1341934	2221	3851	923881	-1559666
S14	Publishing, printing, and reproduction of recorded media	615	480	-566850	90118	1144	820	-637263	163505
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	1708	1782	208581	-227932	6254	5434	-566533	1817817
S16	Manufacture of chemicals and chemicals products	6349	10879	2820283	-7340868	11273	18270	2137865	-9715432
S17	Manufacture of rubber and plastic products	2281	2636	373407	-317827	4184	4520	845629	-264711
S18	Manufacture of other non-metallic mineral products	2336	1108	6401600	3952145	3772	1972	8375210	4833619
S19	Manufacture of basic metals	4058	5550	6914796	-3195357	5890	9060	7638959	-5662094
S20	Manufacture of fabricated metal products, except machinery and equipment	1807	2063	-123144	-263740	3495	3873	-449627	-325817
S21	Manufacture of machinery and equipment	4497	7516	-2421963	-2472024	8650	15946	-4208154	-4455295
S22	Manufacture of office machinery and computers	1031	2714	-1116069	-1103118	1946	5323	-1709730	-1868430
S23	Manufacture of electrical machinery and apparatus	2178	3091	295906	-877481	4004	5367	170536	-1109732
S24	Manufacture of radio, tv and communication equipment and apparatus	1760	3295	-1000601	-1087270	3628	9585	-2485779	-3405318
S25	Manufacture of medical, precision and optical instrum., watches and clocks	646	2416	-1062370	-978125	1422	4354	-1418704	-1305340
S26	Manufacture of motor vehicles, trailers, and semi-trailers	16752	12784	-1445223	3652444	29238	29477	-7007793	-189002
S27	Manufacture of other transport equipment	1647	1207	-481600	348247	3792	3073	-907069	509012
S28	Manufacture of furniture	1348	1514	-1929794	-116827	2630	3255	-2609799	-363741
S29	Recycling	0	0	0	0	0	0	-141	0
S30	Electricity, gas, steam, and hot water supply	20	130	-1161417	-535279	124	118	-2068985	32546
S31	Collection, purification, and distribution of water	0	0	-122995	0	0	0	-192983	0
S32	Construction	9	1	-8973590	6288	8	9	-13875293	-671
S33	Wholesale and retail trade; repair of motor vehicles, and personal goods	4817	648	-1847744	1347952	8713	956	-4491208	2885833
S34	Hotels and restaurants	0	77	-6865166	-42720	0	131	-8187383	-56812
S35	Land transport; transport via pipelines	1712	190	234109	1047930	3385	370	361097	1981387
S36	Water transport	907	21	1431073	1656031	1062	67	1265076	1541025
S37	Air transport	1594	999	1112266	769351	3282	1998	2086625	1605280
S38	Supporting and auxiliary transport activities; activities of travel agencies	1223	1206	213518	8241	2397	1766	195781	265095
S39	Post and telecommunications	432	299	-116726	20420	738	812	-491737	-17996
S40	Financial intermediation	615	476	-267236	50351	1880	1292	-479067	156535
S41	Real estate, renting, and business activities	3861	5232	-1470087	-285063	10346	13125	-2950324	-597048
S42	Public administration and defense; compulsory social security	0	0	-1760759	0	0	0	-2639369	0
S43	Education	0	0	-637634	0	0	0	-1100636	0
S44	Health and social work	0	0	-3666360	0	0	0	-4927300	0
S45	Other community, social, and personal service activities	240	815	-1079053	-221728	776	2050	-1951336	-444452
S46	Private households with employed persons	0	0	0	0	0	0	0	0
	TOTAL	**80994**	**97359**	**-23074501**	**-23074501**	**151658**	**192944**	**-44158135**	**-44158135**

Units: million euros and tonnes of CO_2 equivalent units. Source: own elaboration from the 1995 and 2000 Spanish NAMEA.

Table 4: Key products for the GHG emission balances

From general expression (13)							
1995				**2000**			
S19	+6.9	S32	-9.0	S1	+9.7	S32	-13.9
S18	+6.4	S8	-8.6	S18	+8.4	S8	-8.4
S1	+6.3	S34	-6.9	S19	+7.6	S34	-8.2
S16	+2.8	S44	-3.7	S16	+2.1	S44	-4.9
S36	+1.4	S21	-2.4	S37	+2.1	S33	-4.5
From shortcut expression (14)							
1995				**2000**			
S18	+4.0	S5	-9.4	S18	+4.8	S5	-25.4
S26	+3.7	S16	-7.3	S1	+4.7	S16	-9.7
S36	+1.7	S19	-3.2	S33	+2.9	S19	-5.7
S33	+1.3	S8	-3.2	S35	+2.0	S21	-4.5
S35	+1.0	S21	-2.5	S15	+1.8	S24	-3.4

Unit: million tonnes of CO_2 equivalent.
See Table 3 for sector labels.