INTERNATIONAL TRADE AND EMISSIONS: A MIYAZAWA APPROACH[1]

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RESUMO:

Desde o início da industrialização é possível observar um aumento dos níveis de gases de efeito estufa (GEE) causados pelas atividades humanas. Diante desse cenário, os problemas em torno dos GEE e as mudanças climáticas relacionadas se tornaram relevantes pontos de debate. As discussões sobre o tema começam a ganhar o cenário mundial a partir do Protocolo de Quioto e estão em voga devido ao fato que o crescimento dos GEE se manteve, mesmo com o avanço e surgimento de políticas climáticas. Além disso, estão em voga devido à globalização acelerada das economias mundiais e à expansão do comércio internacional. Desta forma, o trabalho busca fazer uma investigação empírica sobre as responsabilidades pelas emissões e o comércio internacional para 27 países da União Europeia e 13 países selecionados para o período de 1995 a 2009. O trabalho também permeia questões e discussões em torno das teorias e hipóteses ambientais que envolvem o comércio internacional. Para tanto, foram utilizadas matrizes de insumo-produto para 40 países mais o "restante do mundo" que abrangem o período de 1995 a 2009, provenientes do Projeto WIOD. Em termos de resultados, temos indícios de que os decréscimos das emissões de alguns países são provenientes de uma maior interação em termos de comércio.

Palavras-Chave: Emissões de CO_2; Comércio Internacional; Insumo-Produto.

ABSTRACT:

Since the beginning of industrialization it is possible to observe an increase in the levels of greenhouse gas (GHG) emissions caused by human activities. Given this issues, the problem of GHG and related climate change are relevant points today. Discussions began to gain the attention of the world with the Kyoto Protocol and they are in vogue due to the fact that the growth of GHG remained, even with emergence and advancement of climate policies. Moreover, they are in vogue due the sudden globalization of world economies and the expansion of international trade. Thus, this paper seeks to make an empirical investigation of the responsibility for CO_2 emissions and international trade for the 27 countries of the European Union and 13 other selected countries for the period of 1995-2009. This paper also permeates issues and discussions about the environmental theories and hypotheses involving international trade. The input-output matrices were used for 40 countries plus the "rest of world" for the period of 1995-2009, that comes from of the WIOD project. In terms of results, we have evidence that the decrease of CO_2 emissions in some countries comes from high interaction in terms of trade with other countries.

Keywords: CO_2 Emissions; International Trade; Input-Output.

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JEL Classification: C67; Q5**.**

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1. INTRODUCTION

According to the report of World Trade Organization (WTO, 2009), since the beginning of industrialization it is possible to observe an increase in the level of greenhouse gas (GHG) caused by human activities. As a result, the concentration of GHG in the atmosphere has also increased. Given this scenario, the issues around GHG and related climate change are relevant in the global economy discussion.

Debates began to gain the attention of the world with the signing of the Kyoto Protocol in December 1997, where an international agreement was reached to reduce global emissions to the atmosphere (MUNKSGAARD and PEDERSEN, 2001). However, the growth of global CO_2 emissions remained, even with the emergence and advancement of climate policies. From 1990 to 2008 CO_2 emissions in developed countries has stabilized, however emissions in developing countries doubled (PETERS *et al.*, 2011).

International trade has expanded in recent centuries and this is one reason why trade is increasingly being involved with discussions about climate change (WTO, 2009). According to Peters and Hertwich (2006), given that production networks are increasingly global, it is observed that many production processes occur outside the country of final consumption.

Thus, there is a growing concern with the problem of carbon leakage and consequently many studies have taken into consideration the estimated emissions embodied in international trade through, for example, input-output analysis (*e.g.* WYCKOFF and ROOP, 1994; SCHAEFFER and DE SÁ, 1996; LENZEN, 1998; MACHADO et *al.*, 2001; MUNKSGAARD and PEDERSEN, 2001; PETERS and HERTWICH, 2004, 2006).

In this context, it is important to incorporate issues involving GHG emissions and international trade. Moreover, the debate also involves trade liberalization and related environmental consequences of economic growth and international trade (*e.g.* COPELAND and TAYLOR, 1994, 2004; NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002).

Consequently, this paper seeks to make an empirical investigation of CO_2 emissions from international trade for the 27 countries of the European Union and 13 other selected countries for the period of 1995-2009. Furthermore, it permeates issues and discussions around environmental theories and hypotheses involving international trade (*e.g.* the pollution haven effect, the pollution haven hypothesis, trade's patterns of North-South).

The overall aim is to measure emissions embodied in international trade and to analyze the interactions in regional terms, among such countries. We propose the following specific aims: a) to observe the behavior of countries regarding CO_2 emissions, if there is concentration and whether this behavior is maintained over the years 1995-2009; b) to measure CO_2 emissions embodied in production and consumption, c) to measure the CO_2 emissions embodied in exports and imports of each country; d) to verify if the international trade has been used as a way to reduce emissions by countries, and e) to analyze the degree of economic interaction between two regions[5] in terms of pollution (CO_2 emissions); and f) to evaluate environmental hypotheses and theories about CO_2 emissions and international trade.

Thus, this paper seeks to contribute with the use of an interregional input-output model and analyze the economic interactions through Miyazawa multipliers. It is important to note that the choice of the method is given by the ability to look at the interaction effect (interdependence) and the types of synergistic interactions among countries, and the possibility of extension for interactions in terms of CO_2 emissions.

In order to achieve these aims and to have a more detailed view, we use exercises to show the behavior of countries in terms of absolute emissions, economic interactions, and other aspects. This selection is made taking into account the importance of the countries in the global context and with respect to the discussions of international trade and CO_2 emissions.

[5]The choice of regions is given by the importance of these in economic terms, applications and discussions on literature review of emissions and international trade.

Furthermore, it is important to note that the issues around international trade refer to a discussion of the intermediate flows among countries, *i.e.*, only trade relations in terms of the intermediate consumption are taken into account.

In order to contextualize the research problem and achieve these objectives, the present work is divided as follows: besides this introduction, the second section provides a literature review. The third shows the database. The fourth section presents the methodology. The fifth presents the empirical results. Finally, the sixth section presents some concluding remarks.

2. LITERATURE REVIEW

Research efforts have taken into account sustainable consumption. However, according to Tukker *et al.* (2006) although it has been possible to observe some progress, real initiatives for more sustainable consumption have not materialized. Thus, efforts to develop more efficient and effective consumption systems are still unknown, with little practical advance.

Therefore, policymakers are seeking a better understanding of how environmental impacts are related to the choices and specific activities of consumption. In addition, despite some certainties, Tukker *et al.* (2006) argue that there are many gaps unfilled, such as the environmental impacts of consumption in developed countries on trading partners, especially in developing countries.

The assumption behind this, according to Wiedmann *et al.* (2007) is that given the growing demand in the world by the developed countries for imported goods and services, we have consequently increased pollution in the production process in other countries. Thus, in order to reduce GHG emissions it is necessary to investigate not only the major sources of emissions, but also the location of such emissions and the sectors involved.

Despite all the discussion regarding GHG emissions, it is important to take into consideration trade and GHG emissions involved. Furthermore, it is important to consider the literature around the liberalization of international trade and related environmental consequences.

The pollution embodied in trade flows becomes important due to the sudden expansion and globalization of world economies, where demand can be supplemented through international trade. Thus, recent studies have explored and demonstrated that a significant amount of pollution is embodied in international trade (*e.g.* WYCKOFF and ROOP, 1994; LENZEN, 1998; MACHADO *et al*., 2001; LENZEN *et al*., 2004).

However, according to Wyckoff and Roop (1994) many controlling policies are based on reducing domestic emissions of GHG, which ignores, for example, CO_2 emissions embodied in international trade.

Moreover, considering international trade, Antweiler (1996) introduces the concept of pollution in terms of trade and approaches another important question: "Do countries gain or lose environmentally from engaging in international trade?"

As mentioned previously, with the process of globalization, developed countries can achieve their targets for reducing emissions through international trade and/or shift their emissions-intensive production to other countries (WYCKOFF and ROOP, 1994; KONDO *et al.* 1998; WIEBE *et al.* 2012).Therefore, there is a growing concern with the problem of carbon leakage and consequently many studies have taken into consideration the estimated emissions embodied in international trade through input-output analysis (*e.g.* WYCKOFF and ROOP, 1994; MUNKSGAARD and PEDERSEN, 2001; WIEBE *et al.* 2012).

Thus in recent years many studies have tried to develop a more comprehensive approach to measure pollution embodied in trade flows, including contributions that combine input-output analysis and ecological footprint[6] (TURNER *et al*., 2007).

However, beyond this discussion, the debate behind environmental issues also involves discussion around trade liberalization and related environmental consequences. The world economy is in continuous change over the years. The economic activity, population and per capita income

[6] As suggested by Wiedmann *et al.* (2007), the ecological footprint should be estimated based on a multi-regional input-output model. The authors argue that the method is more appropriate and accurate to allocate the total pollution.

showed significant changes. Moreover, the world economy has become more integrated, *e.g.* technological advances in communication and information, the reduction of trade barriers and foreign investment (NORDSTRÖM e SCOTT, 1999).

According Nordström and Scott (1999) with more integrated economies, the costs of international trade transactions substantially reduced, leading to an increase of 14 times in the trade since 1950. However, the evolution and growth of the world economy may be accompanied by environmental degradation (*e.g.* global warming, air pollution). Given this, discussions around international trade, the effects of environmental policy and the environmental consequences of trade liberalization have been made by the environmental community (NORDSTRÖM and SCOTT, 1999; COPELAND and TAYLOR, 2004). Moreover, according to Copeland and Taylor (2004) the debate was intensified with the creation of the World Trade Organization (WTO) and proposals for future rounds of trade negotiations.

Given this discussion around environmental issues, it has been possible to find in the literature many authors who address the environmental consequences of economic growth and international trade (*e.g.* COPELAND and TAYLOR, 1994; NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002; COPELAND and TAYLOR, 2004).

Copeland and Taylor (2004) approach theories and empirical works to answer three questions: “What do we know about the relation among international trade, economic growth, and the environment? How can this evidence help us evaluate ongoing policy debates in this area? Where do we go from here?”

A first theory approached by Copeland and Taylor (2004) is known as the Environmental Kuznets Curve (EKC). According to the authors, the EKC literature postulates a simple relationship between per capita income and pollution. Moreover, according to Atweiler *et al.* (2001) the main issue behind this theory is as follows: "How does economic growth affect the environment?”

The EKC hypothesis is that we have a relation in the form of inverted U between per capita income of a country, economic development, and their level of environmental quality (NORDSTRÖM and SCOTT, 1999; DASGUPTA *et al.*, 2002; COPELAND and TAYLOR, 2004).

However, Dasgupta *et al*. (2002) argue that the model of EKC provoked conflicting reactions of researchers and policymakers, and it has been possible to find at least four different approaches[7]. Besides Dasgupta *et al.* (2002), other authors present different results about the EKC, *e.g.*, Chimeli and Braden (2005) and Chimeli (2007).

Furthermore, despite the relevance and relation between income growth and the environment, Copeland and Taylor (2004) discuss the fact that trade can change the environmental results through a variety of other ways, such as with the displacement of pollution-intensive industries from countries with stringent environmental policies for those with less stringent policies.

According to Atweiler *et al.* (2001), this branch of literature seeks to examine the relation between pollution abatement costs and trade flows and it seeks to answer the following question: "How do environmental regulations affect trade flows?"

According to Copeland and Taylor (2004), the literature has not always been clear about the hypothesis to be tested. The authors show that much of the attention has been directed to three hypotheses of the effect of pollution regulation on trade flows.

The first hypothesis is that strong regulation of pollution has effects on plant location decisions and trade flows - pollution haven effect (COPELAND and TAYLOR, 2004). The second hypothesis, known as pollution haven hypothesis, according to Copeland and Taylor (2004) and Taylor (2005) is a stronger version of the first, because according to this hypothesis, a reduction of trade barriers will lead to a shifting of intensive industry from countries with stringent pollution regulations for countries with weaker regulations, *i.e.*, a trade liberalization leads to a shifting of production of "dirty goods" from countries with stringent regulations (North) for countries with weaker regulation (South).

Finally, the third hypothesis is that the direction of "dirty goods" trade is decided mainly by conventional determinants of comparative advantage and differences in technology. In terms of

[7] For more details see: Dasgupta *et al.* (2002).

effect, Copeland and Taylor (2004) discuss that there is no reason to expect that trade has the same effect in all countries, because the effect of trade liberalization on the environment depends on the comparative advantage of a country.

According to Antweiler *et al.* (2001), a critical approach involving environmental policy, it is that despite being successful in predicting patterns of trade in a world where politics is fixed, their findings may lead to erroneous conclusions in a world where environmental protection is endogenous.

However, the environmental policy involves other considerations. Copeland and Taylor (2004) show two concerns, the first involving the use of environmental policy as a substitute for trade policy, and the second one that involves the use of trade policy to achieve environmental goals.

Furthermore, Chichilnisky (1994) argues that to develop appropriate environmental policies is necessary to understand the connection between markets and the environment. In this context the author raises some questions: Why do developing countries tend to specialize in the production and the export of goods which deplete environmental resources such as rain forests? Do they have a comparative advantage in "dirty industries", and if so, does efficiency dictate that this advantage should be exploited? Is it possible to protect resources without interfering with free markets? Are trade policies based on traditional comparative advantages compatible with environmental preservation?

Besides these issues, another point is approached by Chichilnisky (1994): “How do property rights affect trade?” According to the author, the differences in property rights regimes for environmental resources may be responsible for some aspects of the patterns of trade between North and South.

According to Chichilnisky (1994), the global environment has handled North-South issue, due a concern about the international issues related to the environment. Consequently, there has been a concern in linking environmental policy with economic issues of interest to the industrialized and developing countries (*e.g.* technology transfer). Thus, the problems involving property rights, which arise when societies are in transition from an agricultural to an industrial economy trading with already industrialized societies.

3. DATABASE

The data structure used in this work comes from of the World Input-Output Database (WIOD)[8]. As approached by Timmer (2012), the database was developed to analyze the effects of globalization on trade patterns, environmental pressures and socioeconomic development

Therefore, the data structure of the present work consists of input-output tables for 40 countries[9] (27 EU countries and 13 other selected countries) plus the “Rest of the World” for the period of 1995-2009[10]. It is important to note that these tables have 35 productive sectors. Furthermore, this work also uses atmospheric emissions of CO_2 (in tons) for the same 40 countries selected and the same range of time and sectors.

Given the relevance and focus of this study, it is important to observe the behavior in terms of CO_2 emissions for some countries. Figures 1-4, show the temporal evolution of the emissions of CO_2 to the United States (USA), China (CHN), Brazil (BRA), India (IND) and Russia (RUS), respectively.

Through Figure 1, it is possible to observe that the United States (USA) present a behavior of increasing of CO_2 emissions levels until the year 2000 and from this year present a decrease, except in 2007. Figure 2 shows the results for China (CHN). It is possible to observe a behavior different

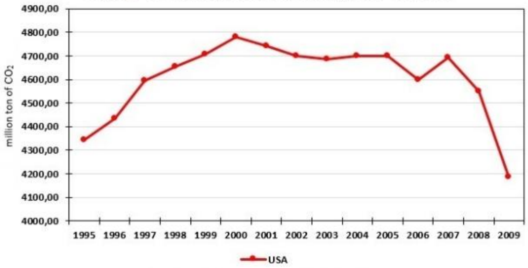
[8] For more details about the WIOD project see: Dietzenbacher *et al.* (2013), Erumban *et al*. (2012a, 2012b), Genty and Arto (2012), Timmer (2012).

[9] Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy , Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Sweden, Slovakia, Slovenia, Spain, Taiwan, Turkey, United Kingdom e United States.

[10] These countries together account for about 85% of world GDP (DIETZENBACHER *et al.*, 2013).

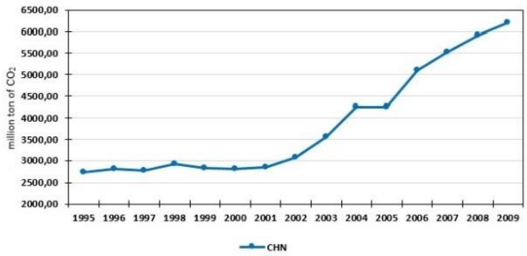
than presented by the United States (USA), because China presents small increases in emission levels for the early years (1995-2001) and from 2002 it presents the more significant additions.

Figure 1 – CO_2 emissions of the United States (USA) – 1995-2009



Source: Own elaboration from WIOD database.

Figure 2 – CO_2 emissions of China (CHN) – 1995-2009

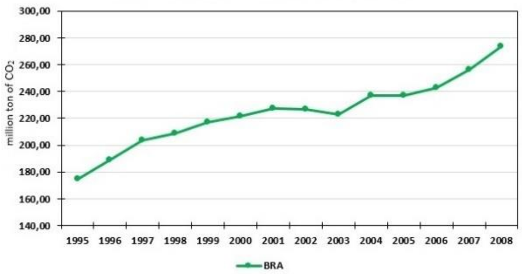


Source: Own elaboration from WIOD database.

For Brazil (BRA), Figure 3, it is possible to observe a behavior similar to observed for China (Figure 6), *i.e.* the country also presents a performance of increase for most of the years, however at lower levels.

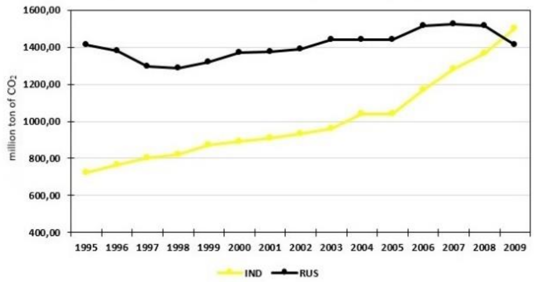
Finally, for India, Figure 4, as well as for Brazil (BRA) and China (CHN), it is possible to observe the behavior of increase in CO_2 emissions over the years (1995-2009). On the other hand, to Russia (RUS), Figure 4, it is possible to observe a behavior with larger oscillations.

Figure 3 – CO_2 emissions of Brazil (BRA) – 1995-2009



Source: Own elaboration from WIOD database.

Figure 4 – CO_2 emissions of India (IND) and Russia (RUS) – 1995-2009



Source: Own elaboration from WIOD database.

Thus, it is possible to observe a different behavior in terms of absolute CO_2 emissions between the United States (USA) and BRIC (Brazil, Russia, India and China), for example. Given that USA and BRIC represent countries with different stages of development, the first is considered developed and the second as developing, important issues presented in the literature review can be discussed, such as: theory of EKC, carbon leakage, the pollution haven effect, the pollution haven hypothesis. In addition, other issues can be addressed, such as differences in the composition of natural fuel reserves of the countries and institutional reforms adopted by them.

However, this result should be seen at first only as an indication and motivation to analyze and test such theories, because other factors may be involved. Furthermore, it is noteworthy that an analysis of these results in the context of these hypotheses and theories is made in a late section.

4. METHODOLOGY

4.1. Input-Output Models (Conceptual Model and Representation)[11]

In order to generalize, the model shown below is described considering an economy with a generic number of *n* sectors. Thus, it is possible to mathematically represent the relationships, as follows:

$$X_i = \sum_{j=1}^{n} Z_{ij} + C_i + I_i + G_i + E_{Xi} \qquad i = 1, 2, 3 \dots n \tag{1}$$

where: X_i = total demand for total output of sector *i*; Z_{ij} = production of sector *i*, sold as intermediate input to sector *j*; C_i = production of sector *i* sold to families; G_i = production of sector *i*, sold to the government; I_i = production of sector *i*, sold as fixed investment; and E_{Xi} = production of sector *i*, sold to abroad, *i.e.* export.

[11] This subsection is based on Miller and Blair (2009), and Guilhoto (2011).

However, it is possible to have an inter-regional input-output model that describes the particular case of this work, *i.e.*, an economy divided into 41 regions (27 EU countries, 13 other selected countries and the "Rest of the World"):

$$Z^{*}i_{41n} + Y^{*} = X^{*} \tag{2}$$

where: Z^{*} = *41nx41n* matrix and it represents the interregional input-output table*;* i_{41n} = unit vector (all elements are equal to 1) with *41nx1* order; Y^{*} = *41nx1* vector and it represents the final demands of the regions, and X^{*} = 41nx1 vector and it represents the production sector of the regions.

Thus, the elements of equation (2) can be represented as follows:

$$Z^{*} = \begin{bmatrix} Z_{ij}^{1,1} & Z_{ij}^{1,2} & \cdots & Z_{ij}^{1,40} & Z_{ij}^{1,41} \\ Z_{ij}^{2,1} & Z_{ij}^{2,2} & & Z_{ij}^{2,40} & Z_{ij}^{2,41} \\ \vdots & & \ddots & & \vdots \\ Z_{ij}^{41,1} & Z_{ij}^{41,2} & \cdots & Z_{ij}^{41,40} & Z_{ij}^{41,41} \end{bmatrix} \quad Y^{*} = \begin{bmatrix} Y^{1} \\ Y^{2} \\ \vdots \\ \vdots \\ Y^{41} \end{bmatrix} \quad X^{*} = \begin{bmatrix} X^{1} \\ X^{2} \\ \vdots \\ \vdots \\ X^{41} \end{bmatrix} \tag{3}$$

Where the interregional input-output matrix is represented by Z^{*}, and the sub-matrices $Z_{ij}^{1,1}$, $Z_{ij}^{2,2}$..... $Z_{ij}^{40,40}$e $Z_{ij}^{41,41}$ are the sub-matrices with intra-regional flows and the other sub-matrices are related to inter-regional flows. The components Y^{1}, Y^{2}..... Y^{40}e Y^{41}; e X^{1}, X^{2}..... X^{40}e X^{41} are vectors *nx1* containing the final demands and product sectorial, respectively.

However, as shown by Guilhoto (2011), assuming that the intermediate flows per unit of final product are fixed, it is possible through the inter-sector flows (Z_{ij}) and the total output (X_i) to determine the technical coefficient.Thus the more convenient way to write the equation (2) is to incorporate technical coefficients (A^{*}):

$$A^{*} = Z^{*}(\widehat{X}^{*})^{-1} \tag{4}$$

Rewriting it:

$$A^{*}X^{*} + Y^{*} = X^{*} \tag{5}$$

Manipulating algebraically equation (5):

$$X^{*} = B^{*}Y^{*} \tag{6}$$

where $B^{*} = (I - A^{*})^{-1}$ corresponds to Leontief matrix for the IR-IP model.

Thus, we can write the interregional model as follows:

$$\begin{bmatrix} X^{1} \\ X^{2} \\ \vdots \\ X^{40} \\ X^{41} \end{bmatrix} = \begin{bmatrix} B^{1,1} & B^{1,2} & \cdots & B^{1,40} & B^{1,41} \\ B^{2,1} & B^{2,2} & & B^{2,41} & B^{2,41} \\ \vdots & & \ddots & & \vdots \\ B^{40,1} & B^{40,2} & \cdots & B^{40,40} & B^{40,41} \\ B^{41,1} & B^{41,2} & & B^{41,40} & B^{41,41} \end{bmatrix} \begin{bmatrix} Y^{1} \\ Y^{2} \\ \vdots \\ Y^{40} \\ Y^{41} \end{bmatrix} \tag{7}$$

4.2. Modeling CO_2 Emissions[12]

Wiebe *et al.* (2012) describes two forms of modeling of CO_2 emissions in such models. The first, suggested by Leontief (1970) uses the technique of adding a row in the matrix Leontief (pollution sector), providing pollution of all the other sections and having total pollution as the sum of the row (*e.g.* LENZEN, 1998; LENZEN *et al.*, 2004; MILLER and BLAIR, 2009; CARVALHO *et al.*, 2013). The second form of modeling, used by Peters and Hertwich and coauthors (*e.g.* PETERS and HERTWICH, 2004, 2006), it is to multiply the Leontief inverse by a matrix of coefficients pollution intensity.

Given that the objective of this study is to model CO_2 emissions in terms of international trade, this paper uses the second method for modeling CO_2 emissions in the context of input-output tables. In such modeling, it is necessary to keep in mind that emissions from one sector refer to the amount of pollution in terms of CO_2 that a sector, in particular, emits to enable its production.

[12] This subsection is based on Wiebe *et al.* (2012).

The intensity coefficient of CO_2 uses (CI's) corresponding to the ratio of CO_2 emission and the total output of sector *i*, *i.e.*:

$$CI_i^n = \frac{ECO2_i^n}{VBP_i^n} \quad (8)$$

where: CI_i^n is the intensity coefficient of use of CO_2 from industry *i* in the country *n*; $ECO2_i^n$ is the CO_2 emissions of the sector *i* of country *n,* and VBP_i^n is the total output of industry *i* in the country *n*.

Therefore, the CI enables us to classify the sector as intensive or not with respect to CO_2 emissions. Furthermore, the CI is the weighting factor of the input-output matrix, where in order to better capture the dependency and CO_2 emissions among countries, the coefficients of intensity are calculated and the following algebraic operations are made:

$$\hat{E} = \begin{bmatrix} CI_i^1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & CI_i^{41} \end{bmatrix} \quad (9)$$

Thus, the matrix $\hat{E}$ is used as follows:

$$B^{¤} = B\hat{E} \quad (10)$$

where $B^{¤}$ represents the Leontief inverse matrix weighted by the emission of CO_2.

Therefore, the input-output model which uses the coefficient matrix of intensity of pollution (CO_2 emission) can be written in matrix form as follows:

$$\pi = \hat{E}X = \hat{E}(I - A)^{-1}Y \quad (11)$$

Substituting (10) into (11) we have:

$$\pi = B^{¤}Y \quad (12)$$

where π is the matrix of pollution.

4.3. Miyazawa Multipliers[13]

As explained by Fritz *et al.* (1998), it is important to make a distinction between polluting and non-polluting sectors of an economy. Thus, the notion of pollution generation, direct and indirect, becomes another factor to be observed. And according to the authors, such relationships can be explored through methodological framework originally proposed by Miyazawa (1966, 1968, 1971) and later extended by Sonis and Hewings (1993, 1995, 1997).

Miyazawa's work consists of an application of internal and external multipliers. Miyazawa internal and external multipliers are derived to partition the Leontief inverse matrix in propagation of internal activity and of external activity, respectively (OKYAMA; SONIS; HEWINGS, 1999).

According to Sesso Filho *et al.* (2006), the methodology allows to classify the types of synergistic interactions between regions and enables us to examine, through internal and external interdependencies, the structure of trade between two regions.

First it is exposed the methodological framework behind Miyazawa multipliers. From this initial decomposition, proposed by Miyazawa and based on Fritz et al. (1998), issues involving pollution (CO_2) can be derived.

Therefore, consider the following input-output system with two regions[14]:

$$\left(\frac{X_{11}}{X_{21}}\middle|\frac{X_{12}}{X_{22}}\right) = \left(\frac{Z_{11}}{Z_{21}}\middle|\frac{Z_{12}}{Z_{22}}\right) + \left(\frac{Y_{11}}{Y_{21}}\middle|\frac{Y_{12}}{Y_{22}}\right) \quad (13)$$

where: Z represents trade flows (intermediate consumption), Y is the final demand. Thus, X equals the total output.

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[13] Based on Fritz, Sonis and Hewings (1998), Sonis and Hewings (1999b), and Okuyama, Sonis e Hewings (1999).

[14] Guilhoto *et al.* (2001) expanded and discussed the methodology proposed by Miyazawa for interregional model at the level of 5 macro regions of the Brazilian economy for the year 1995.

From the vector X and the trade flows matrix (Z), it is possible to obtain the matrix of technical coefficients (direct inputs)[15]:

$$A = \left(\frac{A_{11}}{A_{21}}\middle|\frac{A_{12}}{A_{22}}\right) \tag{14}$$

where $A_{11}$and A_{22} are matrices of direct inputs of the first and second region, respectively. A_{12} and A_{21} are matrices of direct inputs purchased by the first and second regions, respectively.

The matrix A can be presented in a separeted form: "*Pull-Decomposition*". Thus, the first region is decomposed to exert an influence on the second region by "pulling-input" (import) for production from this second region. The same decomposition and interpretation can be made to the second region.

Thus, depending on the used perspective, the off-diagonal entries in equation (14) can be seen as "push" or "pull" linkages with other region:

$$A = \left(\frac{A_{11}}{A_{21}}\middle|\frac{0}{0}\right) + \left(\frac{0}{0}\middle|\frac{A_{12}}{A_{22}}\right) = A_1 + A_2 \tag{15}$$

For purposes of this paper, a hierarchy and methodological framework, where the Leontief inverse matrix is given by

$$B = (I - A)^{-1} = \left(\frac{B_{11}}{B_{21}}\middle|\frac{B_{12}}{B_{22}}\right) \tag{16}$$

The matrices of internal multipliers Miyazawa for the two regions are given by:

$$B_1 = (I - A_{11})^{-1} \tag{17}$$

$$B_2 = (I - A_{22})^{-1} \tag{18}$$

where: B_1 is a matrix multipliers internal for region 1 (country), and B_2 for the region 2.

However, Leontief inverse matrices can be defined as:

$$\Delta_1 = (I - A_{11} - A_{12}B_2A_{21})^{-1} \tag{19}$$

$$\Delta_2 = (I - A_{22} - A_{21}B_1A_{12})^{-1} \tag{20}$$

This matrix Δ_1 can be interpreted, according to Sonis and Hewings (1999b), as the external matrix multiplication of the first region revealing the influence of the second[16]. A similar interpretation can be made to Δ_2.

By equations (14), (17) e (18), the following equations can be obtained:

$$P_1 = A_{21}B_1 \tag{21}$$
$$P_2 = B_1A_{12} \tag{22}$$
$$S_1 = A_{12}B_2 \tag{23}$$
$$S_2 = B_2A_{21} \tag{24}$$

where: P_1 is the matrix multiplier indicating input from Region 1 to Region 2 induced by internal propagation in Region 1. P_2 is the matrix multiplier for internal propagation in Region 1 induced by transactions from Regions 1 to 2. A similar interpretation can be made to $S_1$and S_2, respectively.

Thus, the external matrix multipliers for the regions can be derived as follows:

$$\Delta_{11} = (I - P_2S_2)^{-1} = (I - B_1A_{12}B_2A_{21})^{-1} \tag{25}$$

$$\Delta_{22} = (I - S_2P_2)^{-1} = (I - B_2A_{21}B_1A_{12})^{-1} \tag{26}$$

[15] For more details see Miller e Blair (2009).

[16] Such terminology and interpretation are different from the original definition of the Miyazawa's work as described by Sonis and Hewings (1999b).

Δ_{11} includes direct, indirect and induced effects of sectors of the first region from the input demand effects of the second region. A similar relationship can be established for Δ_{22}.

Having specified and derived the methodology in terms of Miyazawa multipliers, it may extend to the environmental issue, *i.e.* CO_2 emissions.

Thus, for purposes of decomposition of the methodology in terms of pollution (CO_2), the multipliers of equations (19) and (20) are rewritten respectively as follows:

$$\Delta_1 = \Delta_{11} B_1 \quad (27)$$
$$\Delta_2 = \Delta_{22} B_2 \quad (28)$$

As showed by Fritz et al. (1998), the following decomposition of the Leontief inverse matrix, equation (23), can be obtained:

$$(I - A)^{-1} = \begin{pmatrix} \Delta_1 & B_1 A_{12} \Delta_2 \\ \Delta_2 A_{21} B_1 & \Delta_2 \end{pmatrix} \quad (29)$$

The first matrix multiplier of interest in the decomposed Leontief inverse of Eq. (29), $\Delta_2 A_{21} B_1$, reveals the influence of the internal propagation of sectors in Region 1in the level of product of the sectors in the region 2.

In order to evaluate the Region 1 sectors' impact in terms of pollution, the matrix multiplier is premultiplied by a diagonal matrix of pollution coefficients, $\hat{R}$, whose off-diagonal elements are all zero, and thus becomes a pollution matrix multiplier. Then, the matrix of pollution can be obtained:

$$Pol_1 = \hat{R}[\Delta_2 A_{21} B_1] \quad (30)$$

where: Pol_1 is matrix of pollution multipliers whose elements, $p_{i_2 j_1}$, represent the increase in pollution generated by industry i_2 (region 2) as a result of a unit increase in final demand in industry, i_1 (region 1).

In order to evaluate the total amount of pollution generated by a unit increase in a Region 1 industry's output level, the appropriate column multipliers are calculated:

$$m_{j_1} = \sum_{i_2} p_{i_2 j_1} \quad (31)$$

where: m_{j_1} is industry j_1's column multiplier with respect to all the region 2' industries.

The multipliers of the matrix Pol_1 result from the interaction of three multiplier matrices, Δ_{22}, B_2 and B_1, with A_{21}. The sources of pollution induced by the region 1 sectors' production activities can be unveiled by looking at the column sums of these matrices with respect to the region 2 sectors:

i) $\hat{R}A_{21}$ = pollution generated by direct input requirements of Region 1;
ii) $\hat{R}A_{21}B_1$ = pollution caused by direct and indirect input requirements of Region 1;
iii) $\hat{R}B_2A_{21}B_1$ = pollution caused by internal propagation of Region 1 and the induced direct and indirect production of Region 2;
iv) $\hat{R}\Delta_{22}B_2A_{21}B_1$ = total pollution multiplier of Region 1 with pollution caused by the internal propagation of Region 1 and the induced internal and external propagation of Region 2.

The sum of the column industries j_1 in *i, ii, iii* e *iv* are termed as: $m_{j_1}^1$, $m_{j_1}^2$, $m_{j_1}^3$ e m_{j_1}, respectively. Thus, the following definitions may be employed in the empirical analysis:

i) $m_{j_1}^1$ = direct input requirements in the total multiplier;
ii) $m_{j_1}^2 - m_{j_1}^1$ = indirect input requirements in the total multiplier;
iii) $m_{j_1}^3 - m_{j_1}^2$ = internal propagation of Region 2 in the total multiplier;
iv) $m_{j_1} - m_{j_1}^3$ = external propagation of Region 2 in the total multiplier.

Similarly, we can derive and investigate the influence of region 2 in the product of region 1.

5. RESULTS

5.1. Intensity Coefficients of CO_2 Emissions

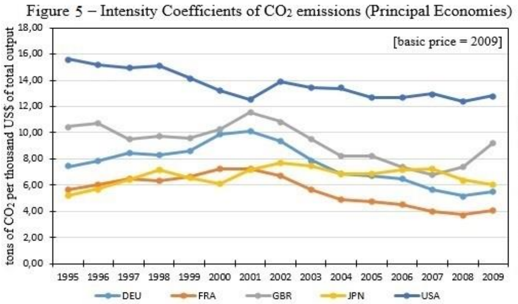
From the input-output model and the availability of CO_2 emissions, it is possible to obtain aggregated indicators for different countries. The intensity coefficients of CO_2 emissions enable us to classify the country as intensive or not with respect to CO_2 emissions. Moreover, these coefficients enable us to incorporate CO_2 emissions in the input-output model by matrix $\hat{E}$ (Equation 9).

It is important to note that the intensity coefficients of emission were calculated for the 40 countries plus the "Rest of the World". However, for this paper Figures 5 and 6 show the results for the United States (USA), Germany (DEU), France (FRA), United Kingdom (GBR) and Japan (JPN), and China (CHN), Brazil (BRA), India (IND) and Russia (RUS), respectively[17].

From Figure 5, it is possible to observe, in general, a decrease in the magnitude of the intensity coefficient of CO_2 emissions for selected countries (DEU, FRA, GBR, JPN and USA), representing a scenario of production with lower CO_2 emission intensity. However, it is important to keep in mind that this does not necessarily reflect a decrease in the absolute amount of CO_2 emissions.

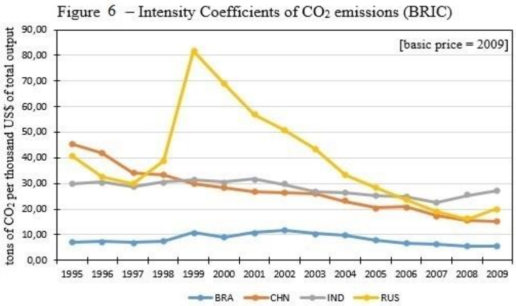
This point of discussion becomes even more relevant when it is observed the intensity coefficients in developing countries, for example. Through Figure 6, we can observe that the intensity coefficients of CO_2 emissions for developing countries (Brazil, Russia, India and China) exhibit a behavior of decrease. However, as shown below, such countries have for the same period a behavior of increase in terms of absolute emissions of CO_2.

Figure 5 – Intensity Coefficients of CO_2 emissions (Principal Economies)



Source: Own elaboration from WIOD database.

Figure 6 – Intensity Coefficients of CO_2 emissions (BRIC)



Source: Own elaboration from WIOD database.

For this study, the coefficients of intensity of CO_2 emissions are more important in methodological terms than in terms of the result itself, since they are used to incorporate CO_2 emissions in international trade, this allow us to obtain results and discussions with regard to CO_2 emissions and international trade.

Thus, the results and discussions involving emissions and international trade are presented in the next two sections (5.2 Trade balances of Global CO_2 Emissions and 5.3 Miyazawa Multipliers).

5.2. Trade balances of Global CO_2 Emissions

The input-output models, as discussed by Wiebe *et al.* (2012), allow us to obtain indicators of production and consumption of CO_2 emissions to countries and regions, for example, taking into account the emissions embodied in international trade.

The carbon trade balances are calculated from matrix π (equation 12) for all countries[18] for the years 1995, 2000, 2005 and 2009, respectively. However, it is noteworthy, as the strategy used by Wiebe et al. (2012) and adapted to the database of this study, for purposes of calculating the trade balance of CO_2 emissions, the π matrix is aggregated in a 41x41 trade matrix (number of spatial units, *i.e.* 40 countries plus the "rest the world"), showing the sales in terms of CO_2 for each country in the rows and the purchases in terms of CO_2 in the columns. Thus, from this matrix is done the calculus of the carbon trade balances for each country. Imports are derived from the sums of the rows, except the diagonal elements, and exports come from the column sums, again except the diagonal.

[17] This selection has the intention to motivate through these preliminary results, discussions of hypotheses and theories around environmental issues.

[18] Complete results are available from the authors.

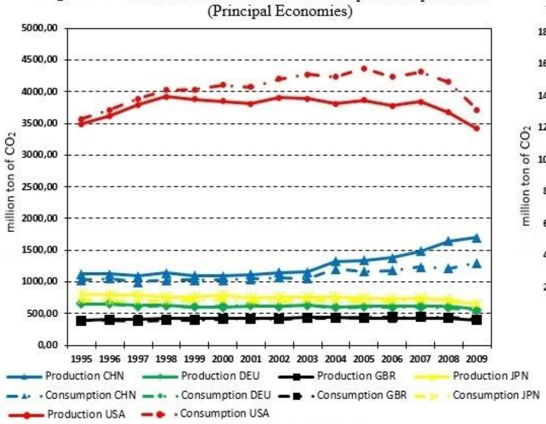
Thus, overall emissions embodied in the production and consumption are associated with the intermediate flows between 40 countries plus the "Rest of the World". Pollution embodied in production is the CO_2 emissions associated with the sale of inputs by a spatial unit (one country to the other 39 countries plus the "Rest of the World"). And similarly, pollution embodied in consumption corresponds to the emissions associated with the acquisition of inputs.

For comparison, Figure 7 shows the evolution of global trade balances of CO_2 emissions embodied in international trade[19], *i.e.*, emissions embodied in consumption (dotted lines) and production (solid lines) for five countries: China (CHN) , Germany (DEU), United Kingdom (GBR), United States (USA), and Japan (JPN).

Thus, with the Figure 7, on the one hand, we can see that for the USA the dotted line is above the solid line, *i.e.*, CO_2 emissions embodied in consumption are higher than the emissions embodied in production for the years 1995-2009. On the other hand, for GBR the line solid (production) is above the dotted line (consumption) until the year 2004, exhibiting similar behavior to USA only from 2005. For DEU, it is possible to observe a behavior with oscillations between the years 1995 to 2003 and from 2004 presented in conduct contrary to the USA, with CO_2 emissions embodied in production larger than emissions embodied in consumption.

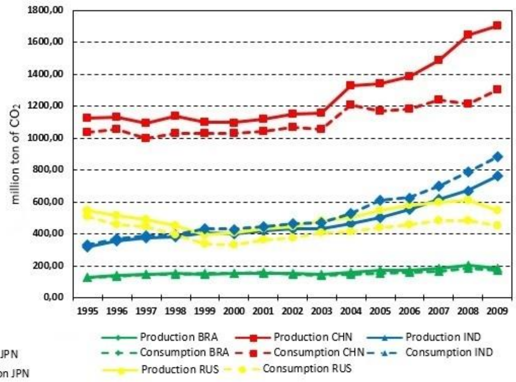
Finally, for JPN and CHN, it is possible to see that the solid line is above the dotted line, *i.e.*, contrary to the behavior exhibited by the USA, for these two countries CO_2 emissions embodied in production are higher than emissions embodied in consumption for the years 1995 to 2009.

Figure 7 – CO_2 emissions embodied in consumption and production (Principal Economies)



Source: Own elaboration from WIOD database.

Figure 8 – CO_2 emissions embodied in consumption and production (BRIC)



Source: Own elaboration from WIOD database.

Similarly, Figure 8 shows the evolution of global trade balances of CO_2 emissions embodied in international trade, *i.e.*, emissions embodied in consumption (dotted lines) and output (solid lines), for a range of different countries: Brazil (BRA), Russia (RUS), India (IND) and China (CHN).

On the one hand, RUS exhibits similar behavior to that presented by CHN with the solid line above the dotted line, *i.e.*, CO_2 emission embodied in the production being higher than the emission embodied in the consumption for the years 1995-2009. BRA, also, presents a solid line above the dotted line, for most years, except 1999-2001. However, on the other hand, IND shows a different behavior, with the CO_2 emissions embodied in the consumption higher than CO_2 emissions embodied in production, for the years 1995 to 2009.

Figure 9 shows, for comparison purposes, results of trade balances of some economies such as the United States (USA), Germany (DEU), France (FRA), United Kingdom (GBR), Japan (JPN), Russia (RUS), China (CHN), Brazil (BRA) and India (IND). Thus, through this figure we can see which of these countries are classified as net importers of CO_2, and which are classified as net exporters of CO_2[20] for the years 1995, 2000, 2005 and 2009.

[19] Note that emissions embodied in international trade correspond to the emissions associated with intermediate flows of input-output tables.

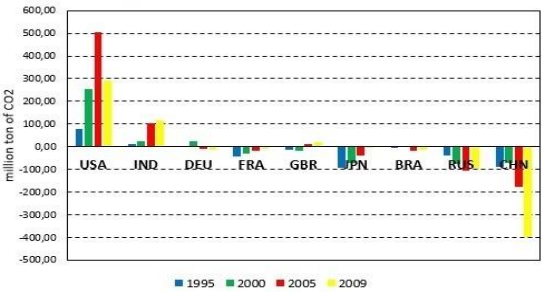
[20] It is noteworthy that net importer and net exporter terms refer to the balance of CO_2 emissions embodied in international trade.

The USA was the country with the highest net imports of CO_2 for the four years in question, with a growth until 2005, more than tripling its net imports of CO_2, and a decrease in 2009. On the other hand, the country with the highest net export of CO_2 for the year 1995 was JPN, for the year 2000 RUS, and for the years 2005 and 2009 CHN. Moreover, it is important to emphasize the growth evidenced by CHN, where the net export of CO_2 quadruples when comparing 1995 with 2009.

Regarding the classification of countries as exporters or importers of CO_2, it is possible to observe USA and IND as net importers in the four years (1995, 2000, 2005, and 2005). On the contrary, FRA, JPN, CHN and RUS are classified as net exporters in these four years.

However, some countries such as BRA, DEU and GBR have different behavior over the years. DEU, for example, in the first two years, 1995 and 2000, is classified as a net importer of CO_2; however, in 2005 and 2009 it reverses and goes on to present a profile of a net exporter of CO_2. Regarding GBR, the pattern is given contrary to DEU; it is possible to observe a profile of net exporter in the first two years and a net importer in the last two years. Finally, BRA is classified as a net exporter in 1995, 2005, and 2009, and classified as a net importer only the year 2000.

Figure 9 – Net Imports and Net Exports of CO_2 emissions



Source: Own elaboration from WIOD database.
Note: Positive values indicate net importers of CO_2 and negative values indicate net exporters of CO_2.

It is important to note that these results have similarities and differences with respect to other studies involving the same subject. The work of Wiebe *et al.* (2012), the basis for the methodology developed in this section shows, for example, similar results for the United States (USA), Germany (DEU), Russia (RUS), China (CHN), *i.e.* these countries have the same behavior in terms of classification (net exporter or net importer of CO_2 emissions), with differences in the magnitude, which is justified by the use of different databases. However, it is also possible to observe different results for India (IND), France (FRA) and United Kingdom (GBR).

Given the results of this section, and according to the purpose of this study, it is important to analyze the structure of trade among the countries. In order to contribute to the literature on international trade and emissions, the next section presents the results for the Miyazawa multipliers.

5.3. Miyazawa Multipliers[21]

As described above and demonstrated by Hewings *et al*. (2001), the Miyazawa multiplier, external and internal, feature the degree of economic interaction between the two regions through the activities propagation of external and internal, respectively. However, for this study the Miyazawa multipliers able us to classify the structure of trade between two regions in terms of CO_2 emissions, such as the application made by Fritz *et al*. (1998).

Furthermore, it is noteworthy that as presented by Hewings *et al.* (2001), Miyazawa multipliers can be derived by an interregional system with more than two regions, however, the calculation of these multipliers requires the specification of the hierarchy (order) of propagation. So with a system with n-regions, it is possible to construct (n+1)!/2 combinations of "routes" of propagation[22].

[21]For details on application and methodology see: FRITZ *et al* (1998); HEWINGS *et al.* (2001); OKUYAMA *et al.* (1999); SONIS and HEWINGS (1993, 1995, 1999a, 1999b); SONIS, M. *et al.* (1997); MIYAZAWA (1966, 1968, 1971).
[22] For an extension of this approach, see Guilhoto *et al.* (2001).

The strategy used in this work is the pre-set pairs from the results found in previous sections, according to the literature and importance of the countries in the global context, and regarding the discussions about international trade and CO_2 emissions. Thus, the Miyazawa multipliers for this paper are calculated by taking pairs, the countries adopted as internal region (specified as R1 in the figures) at first are considered as external region later (specified in the figures as R2), such as example in Figure 10, where China (CHN) is considered the internal region and the United States (USA) the external region, however, in Figure 11, such specification is reversed.

Thus, Figures 10-17 show the results of Miyazawa multipliers in terms of pollution for some pairs of countries. Note that the results represent the average of the Miyazawa multipliers, *i.e.*, the values of the figures are the average of 35 productive sectors for each countries and years.

The results represent the increase of pollution generated by the external region (R2) industries as a result of the increase of US$1.00 in the final demand of the internal region (R1). Thus, it is possible to observe the pollution generated by the direct requirement of inputs for the internal region, pollution caused by the indirect requirement of inputs for the internal region, internal propagation of external region (pollution induced by direct and indirect production of the external region) and external propagation from the external region[23]. Furthermore, the figures show the values for four specific years, 1995, 2000, 2005 and 2009.

The first figure (Figure 10) shows the results for economic interaction in terms of pollution (CO_2 emissions) to China (CHN) and the United States (USA), *i.e.*, the influence of internal propagation of China (CHN) in the level of pollution in the United States (USA).

Through the Figure 10 it is possible to observe that the pollution generated by the direct and indirect requirement of inputs of China (CHN) in the United States (USA), blue and red line, respectively, exhibit a similar behavior over the years, falling at first (1995 to 2000), and increasing thereafter (2005 to 2009).

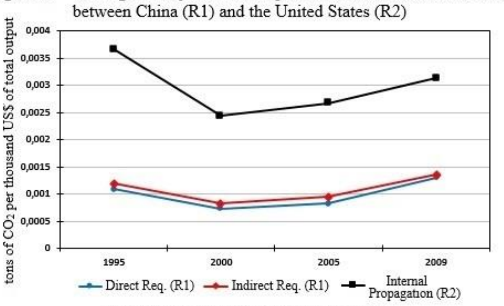
However, the highlights are the results found for the pollution caused by the internal propagation of own United States (USA), black line, because it is possible to observe a decreasing trend, which represent an internal production process less polluter.

The result becomes even more relevant when it is considering the multiplier of the second figure (Figure 11), which shows the results for economic interaction in terms of pollution (CO_2) of the United States (CHN) and China (CHN), *i.e.* the influence of the internal propagation of the United States (USA) at the level of pollution in China (CHN).

From Figure 11 it is possible to observe an opposing behavior when the pollution caused by China's own internal propagation (CHN), given a monetary increase of one unit (US$) in final demand of United States (USA), is analyzed. Differently what it is observed for the United States (USA), China (CHN) exhibits a behavior increased over the years, which represent a more polluter internal process.

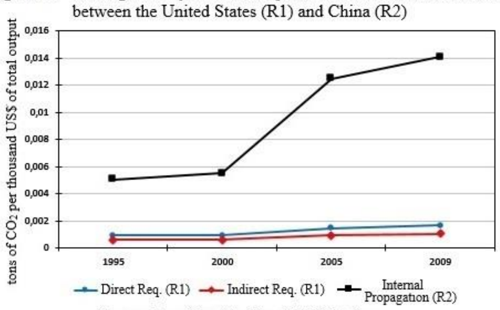
Moreover, in terms of pollution generated by the direct and indirect requirement of inputs of the United States (USA) in China (CHN), the behavior is similar over the years, with a tendency to increase (Figure 11).

Figure 10 – Average of Miyazawa Multipliers of Pollution due interaction between China (R1) and the United States (R2)



Source: Own elaboration from WIOD database.

Figure 11 – Average of Miyazawa Multipliers of Pollution due interaction between the United States (R1) and China (R2)



Source: Own elaboration from WIOD database.

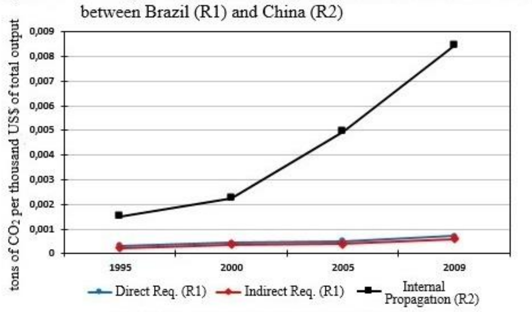
[23] The results for the external propagation are not shown in the figures, because they are characterized by low values due to their own methodological character.

Figure 12 shows the results for economic interaction in terms of CO_2 emissions for Brazil (BRA) and China (CHN). In other words, it brings the influence of internal propagation of Brazil (BRA) in the level of pollution of China (CHN).

Thus, by Figure 12, it is possible to observe that the pollution generated by the direct and indirect requirement of inputs from Brazil (BRA) in China (CHN), blue and red line, respectively, show a similar behavior of increase over the years. However, as it is observed for the United States (USA) and China (CHN), the highlights are the results found for the pollution caused by own internal propagation of China (CHN), black line, because it is possible observe a clear trend of increase, which is, as mentioned earlier, an internal production process more polluter.

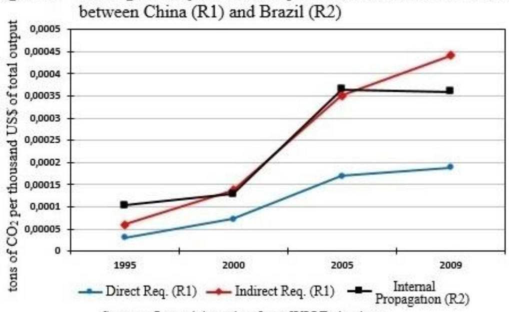
When the analysis is inverted, the pollution generated by the direct and indirect requirement of inputs of China (CHN) in Brazil (BRA), Figure 13, it is possible to observe a behavior of increase, however, with different magnitudes. Moreover, in terms of results for the pollution caused by internal propagation of Brazil (BRA), black line, it is possible to observe a similar behavior presented by China (CHN), *i.e.*, a tendency to increase, representing an internal process productive more polluter. However, for Brazil, Figure 13, between 2005 and 2009 it is possible to see a decrease.

Figure 12 – Average of Miyazawa Multipliers of Pollution due interaction between Brazil (R1) and China (R2)



Source: Own elaboration from WIOD database.

Figure 13 – Average of Miyazawa Multipliers of Pollution due interaction between China (R1) and Brazil (R2)



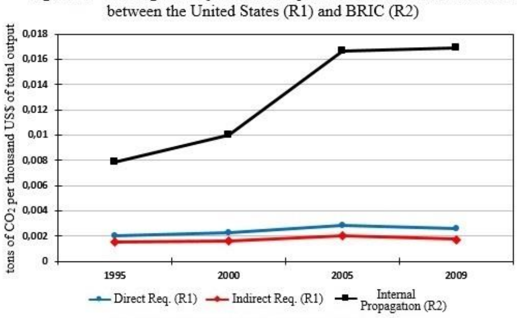
Source: Own elaboration from WIOD database.

Figures 14 and 15 bring the results to the economic interaction in terms of pollution (CO_2) for the United States (USA) and the BRIC. From Figure 14, it is possible to observe that the pollution generated by the direct and indirect requirement of inputs by United States (USA) in BRIC, blue and red line, respectively, exhibit a similar behavior over the years, an increase from 1995 to 2005 , and from this an behavior of decrease.

However, the highlights are the results found for the pollution caused by the internal propagation of BRIC, black line, because it is possible to observe a tendency to increase until 2005, which represent an internal productive process more polluter, and from 2005 to 2009 an inverse behavior (decrease).

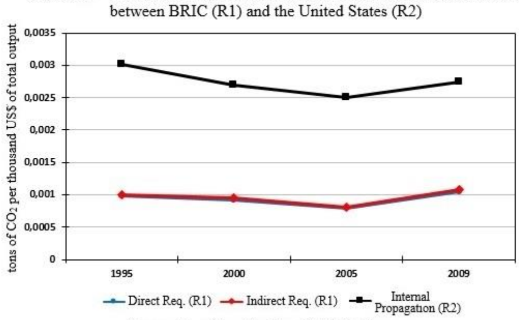
In terms of results for the influence of the internal propagation of BRIC in the level of pollution in the United States (USA), Figure 15, it is possible to observe an opposing behavior for pollution caused by internal propagation of the United States (USA) in comparison with what is seen to BRIC (Figure 14), *i.e.* internal production process less polluter.

Figure 14 – Average of Miyazawa Multipliers of Pollution due interaction between the United States (R1) and BRIC (R2)



Source: Own elaboration from WIOD database.

Figure 15 – Average of Miyazawa Multipliers of Pollution due interaction between BRIC (R1) and the United States (R2)



Source: Own elaboration from WIOD database.

Finally, Figures 16 and 17 show the results to the economic interaction in terms of pollution to the European Union (EU) and the BRIC.

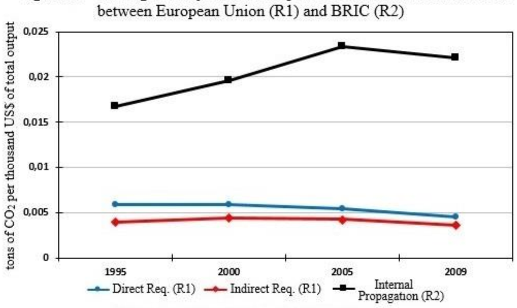
At Figure 16 it is possible to observe the influence of internal propagation of the European Union (EU) in the level of pollution of BRIC, where the pollution generated by the direct and indirect requirement of inputs of the European Union (EU) in BRIC, blue and red line , respectively, show a similar decreasing behavior.

Moreover, with respect to pollution caused by internal propagation BRIC, black line, it is possible to verify a tendency of increase, which represents an internal production process more polluter until the year 2005 and contrary a behavior of decrease from 2005 to 2009.

When the analysis is reversed, *i.e.*, the pollution generated by the direct and indirect requirement of inputs of BRIC in the European Union (EU), Figure 17, it is possible to see that they also show a similar behavior, *i.e.*, both exhibit a behavior of increase between 1995 and 2000 and from that, a decrease behavior (*i.e.* 2000 to 2005, 2005 to 2009).

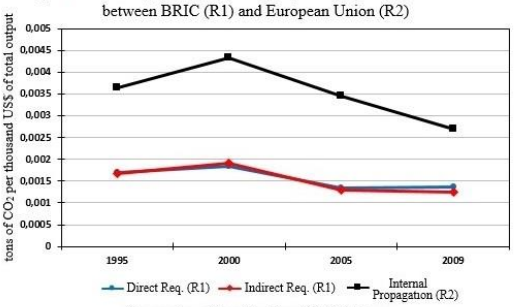
In terms of pollution caused by internal propagation of the European Union (EU) two different scenarios are observed, first representing a more polluter production process (1995-2000) and then a reverse production process, less polluter (2000-2009).

Figure 16 – Average of Miyazawa Multipliers of Pollution due interaction between European Union (R1) and BRIC (R2)



Source: Own elaboration from WIOD database.

Figure 17 – Average of Miyazawa Multipliers of Pollution due interaction between BRIC (R1) and European Union (R2)



Source: Own elaboration from WIOD database.

The results of this section allowed us to analyze the structure of trade relations among the countries in terms of pollution (CO_2 emissions). Thus, in the next section we will make a discussion and analysis of all the results of this work.

5.4. DISCUSSION

Given these results and discussions described in the literature review, an analysis in terms of developed and developing countries seem to be relevant. Through Figures 1-4, we can think about such discussion, because there is an evidence, on the one hand, of increase in emissions from the United States (USA), developed country, in the first instance and subsequently a high decrease. On the other hand, there is a contrary evidence to China (CHN), Brazil (BRA), India (IND) and Russia (RUS), developing countries.

In terms, for example, the theory of EKC, as approached before, this result may be an evidence that the increase in income is associated with an increase in pollution in early stages of economic development and a decline in pollution in more advanced stages. However this is not the main focus of this work, so it is not done any empirical test to evaluate this hypothesis.

However, other hypotheses can be discussed, such as carbon leakage. These results can be linked in some way to a carbon leakage from developed to developing countries. Even more specifically, it can be represented, for example, the use of international trade to reduce CO_2 emissions.

Another hypothesis that can be evaluated is the pollution haven effect, *i.e.* a pollution regulations taking effect on plant location decisions and trade flows. Or even more strongly, that a reduction in trade barriers is leading to a shift of pollution-intensive industry in countries with stringent rules for countries with weaker regulations (pollution haven hypothesis).

However, despite the results of the absolute emissions presented evidence that they can apply and discuss some of the theories, before drawing conclusions, it is necessary to look at the results around the international trade, which for this study consists of the results extracted from of input-output tables: (a) Trade Balance of Global CO_2 Emissions; and (b) Miyazawa Multipliers.

Through the first results, it is possible to present a discussion of responsibility for emissions and consider the different behaviors in terms of developed and developing countries, for example. Given the results presented in Figures 1-4 (absolute emissions) it is observed that developing countries present behavior of increase in CO_2 emissions.

However, such results may lead to erroneous conclusions and attributions of responsibility for emissions, because they consider only the territorial emissions. When we observe, for example, the evolution of the global balances of CO_2 emissions embodied in international trade, *i.e.,* emissions embodied in consumption and production, different evidence and conclusions can be made.

Taking as exercise the global balances of CO_2 emissions of the United States (USA) and the BRIC (Brazil, Russia, India and China), for example, Figures 7 and 8, it is possible to observe different results compared to those presented for emissions absolute CO_2.

On the one hand, the United States (USA) have CO_2 emissions embodied in consumption higher than emissions embodied in production for the years 1995-2009. On the other hand, China (CHN) and Russia (RUS) have emissions CO_2 embodied in production higher than emissions embodied in consumption for the years 1995 to 2009. Brazil (BRA), shows a similar behavior of Russia (RUS) and China (CHN) with except from 1999 to 2001. Finally, India (IND) have a differently behavior, CO_2 emissions embodied in consumption higher than CO_2 emissions embodied in production for the years 1995-2009. Thus, it is possible to affirm that the United States (USA) and India (IND) are classified as net importers of CO_2, and China (CHN), Brazil (BRA) and Russia (RUS) are net exporters of CO_2.

These exercises show interesting results around international trade, however, as described in the previous section, the results concerning the trade structures among countries, Miyazawa multipliers, can contribute further in terms of the relationship between international trade and CO_2 emissions.

Given the results described in the previous section, it is possible to observe, for example, that when you have the pairing between the United States (USA) and European Union (EU), developed countries, with China (CHN), developing country, the result is similar. An increase of a US$1.00 in the final demand in China (CHN) in terms of pollution in the United States (USA) is lower over the year, *i.e.*, evidence that the internal production process of the USA is increasingly less polluter.

The result of the pairing becomes more attractive when it reverses the analysis and the shock of final demand, *i.e.*, an increase of a US$1.00 in the final demand is given in the United States (USA) in relation to China (CHN). It is observed that the internal production process of China (CHN) is more polluter, given the interaction.

Consider other pairings between developed and developing countries, it is possible to see similar results. The pairing between USA and BRA, or between the United States (USA) and European Union (EU) with the BRIC, it is possible, on the one hand, observe an internal production process more polluter of developing countries and blocks (Brazil and BRIC) and, on the other hand, a production process less polluter for developed countries and blocks (EU and USA).

When the analysis is done in terms of interaction between two developing countries (South-South) as Brazil (BRA) and China (CHN), it is possible to observe a more polluter domestic production process.

Given these results for the pre-defined pairings and thinking about the discussions described in the literature review lead us to raise questions about the theories behind the carbon leakage, the pollution haven effect, the pollution haven hypothesis, the use of environmental policy as a substitute for trade policy, the use of trade policy to achieve environmental goals, and patterns of trade between North and South, for example.

The results for China (CHN), for example, always have a more polluter production process, which can be interpreted as a carbon leakage, where countries that have a trade relation with China (CHN) may be taking advantage of international trade to reduce their emissions. Looking at these results plus global trade balances of CO_2 there is further evidence that international trade is being used to reduce emissions.

Given these results, as it was discussed for absolute emissions, it is possible to make a question: do we have a case of pollution haven effect? Although the present study does not provide evidence for the regulation by countries, it is possible to present a simple discussion, because the literature points to a situation where Northern countries have strong regulations and Southern countries a weak regulations (*e.g.* Copeland and Taylor 2004 and Taylor, 2005)

Given that we have examples of North-South pairings (*e.g.* the United States and China, the United States and BRIC) with South increasingly more polluter and North less polluter, it is possible to think that regulation can be affecting the location decisions of plants, for example. Or even more strongly, that a reduction in trade barriers can lead the shift of pollution-intensive industry from countries with stringent regulations (North) to countries with weaker regulations (South), a hypothesis known as the pollution haven hypothesis.

However, although the results present evidence that such theories may be occurring, it is necessary to interpret the results with caution, because these results represent only an exercise.

6. CONCLUSIONS

As shown in this work, the problem of GHG and related climate change is an important debate in international economies, where research efforts have increasingly taken into account sustainable consumption. However, although it has been possible to observe some progress, real initiatives for more sustainable consumption have not materialized. Thus, efforts to develop more efficient and effective consumption systems are still unknown, with little practical advance (Tukker *et al.*, 2006).

In terms of contribution, for example, the present study sought through multipliers Miyazawa address the issues of feedback loop among countries. Furthermore, this study used a solid database (WIOD project) in terms of compatibility of Input-Output Tables and atmospheric CO_2, the same range of time and sectoral disaggregation.

The following results can be highlighted: i) the increase of CO_2 emissions in developing countries (*e.g.* Brazil , Russia, India and China); ii) the opposing behavior of the USA and BRIC, with the exception of India, in terms of net balances of emissions embodied in international trade; iii) evidence that the decrease of CO_2 emissions in some countries comes from greater interaction in terms of trade with other countries; iv) the developed countries have an internal production process increasingly less polluter, and contrary to, developing countries have an internal production process more polluter, given the pairing between them.

Furthermore, this study, through the different results, makes a discussion around environmental theories and hypotheses involving international trade.

Although the results present evidence that such theories may be occurring, it is necessary to interpret the results with caution, as these results represent an exercise. Although it is possible to note a pattern, it is important to observe other interactions, because countries interact differently. In general the relation of cause and effect relation between emissions and international trade has other components, *e.g.* cost, capital mobility and hand labor, which are not addressed in the scope of this work.

Furthermore, it is noteworthy that it is not the scope of this paper to discuss and present all pairings that can be performed using as a basis the 41 spatial units (*i.e.* 40 countries plus the "Rest of the World"). The pairings chosen sought to highlight the issues related to the integration process among countries and the impact on emissions. The choice of pairings can also take into consideration components sociological and political-economy, for example. This may be a possible extension of this work.

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