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International trade, pollution, and economic structure: evidence on CO_2 emissions for the North and the South

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ABSTRACT

This study investigates the mechanics of international trade and CO_2 emissions in two blocs of countries ('North' and 'South') by analyzing data from the World Input–Output Database. We adapt the Miyazawa technique to estimate the linkages between international trade and the environment at a global scale. Therefore, this study is in line with the idea of highlighting the role of feedback effects as well as the nature and extent of extra-regional influences on an economy in response to an additional stimulus. This is a contribution that, to our best knowledge, has not yet appeared in the literature. Our results suggest that both the North and the South have become less pollution-intensive (technique effect) over the years. Interestingly and in contrast to much of the literature, we also find support to the hypothesis that the South has specialized in relatively more pollution-intensive activities (composition effect).

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1. Introduction

International trade is thought to influence trans-frontier pollution due to increased economic activity (scale effect), changes in pollution intensity due to different factor prices, technological changes and comparative advantages (technique effect), and migration of polluting industries to countries with ill-defined property rights and less stringent environmental policies (composition effect). Grossman and Krueger (1991), Chichilnisky (1994), Copeland and Taylor (1994) and Antweiler et al. (2001) are some studies that have made contributions to the theme of trade and the environment. Further, this debate extends to climate change to the extent that trans-frontier pollution can undermine national policies for the provision of a global public good.

Copeland and Taylor (2004) discuss the fact that trade can change the environment through a variety of ways and, according to the authors, the literature has not always been clear about the hypotheses to be tested. The authors show that much of the attention has been directed to some hypotheses of the effect of pollution regulation on trade flows (e.g. Pollution Haven Effect (PHE), Pollution Haven Hypothesis (PHH), and comparative advantage and differences in technology).

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The PHE captures the idea that stringent pollution regulation affects industry location decisions and trade flows. The PHH, according to Copeland and Taylor (2004) and Taylor (2005), is a stronger version of the PHE in the sense that a reduction of trade barriers will lead to a shifting of pollution-intensive industries from countries with stringent pollution regulations to countries with weaker regulations, that is, trade liberalization leads to a shifting of production of 'dirty goods' from countries with stringent regulations (North) to countries with weaker regulations (South).[1] Finally, a third hypothesis postulates that the direction of trade of 'dirty goods' is determined mainly by conventional determinants of comparative advantages and differences in technology.[2]

Furthermore, some studies that try to understand the relationship between trade systems and the asymmetries involving more and less-developed countries. These studies include investigation of production processes and specialization in different regions (e.g. Muñoz et al., 2011).

The increasing volume of international trade and growing concern with global pollution in recent decades gave rise to an expanding literature on the impact of trade liberalization on the environment. Levinson (2009), Douglas and Nishioka (2012), Brunel (2014), Levinson (2015), and Shapiro and Walker (2015) are recent examples of the numerous studies with significant contributions to the topic. However, most studies are silent about the evolving economic structure of trade partners and how they interact in a way to clearly identify the contribution of trade to emissions. Interregional input–output (I–O) matrices can offer a basic framework to fill this gap, especially as we seek to better understand pollution intensities (technique effect) and pollution related to regional economic structures (composition effect) over time. Turner et al. (2007) and Wiedmann et al. (2007) argue in favor of using a multi-region and multi-sector I–O framework to evaluate environmental impacts from the trade of goods and services.[3]

Using the I–O methodology, Wyckoff and Roop (1994), Schaeffer and De Sá (1996), Kondo et al. (1998), Lenzen (1998), Proops et al. (1999), Machado et al. (2001), Munksgaard and Pedersen (2001), Muradian et al. (2002), Machado (2002), Ahmad and Wyckoff (2003), Peters and Hertwich (2004), Lenzen et al. (2004), Sánchez-Chóliz and Duarte (2004), Gallego and Lenzen (2005), Hoekstra and Janssen (2006), Peters and Hertwich (2006), Rodrigues et al. (2006), Mongelli et al. (2006), Turner et al. (2007), Wiedmann et al. (2007), Peters (2008), Nakano et al. (2009), Carvalho and Perobelli (2009), Davis and Caldeira (2010), Davis et al. (2011), Peters et al. (2011), Su and Ang (2011), Wiebe et al. (2012), Cadarso et al. (2012), Carvalho et al. (2013), Moran et al. (2013), Xu and Dietzenbacher (2014), Arto and Dietzenbacher (2014), Liu and Wang (2015), Fernández-Amador et al. (2016), Jayanthakumaran and Liu (2016), Malik and Lan (2016), Malik et al. (2016) and Hoekstra et al. (2016) have contributed to the literature through a discussion of issues inherent to emissions of greenhouse gases and their relationship with international trade. In general, these studies have shown that a significant amount of pollution is embodied in

[1] Thus, given the definitions it is important to note that the existence of a PHE is usually necessary, but not sufficient to ensure the PHH because an indirect evidence of PHH can be provided from other sources (Copeland and Taylor, 2004).
[2] See Copeland and Taylor (2004) for a detailed discussion on these hypotheses.
[3] Turner et al. (2007) describe the method that considers the resources and/or pollution embodied in international trade and Wiedmann et al. (2007) provide a detailed survey review on the recent and more sophisticated multi-region and multi-sector I–O framework used to evaluate the environmental impacts from trade of goods and services.

international trade. In other words, the authors have argued that it is important to look at the linkages between emissions and international trade.

In this context, we build and analyze a two-region I–O model with a methodology to explicitly isolate the contribution of international trade to trans-frontier pollution. We investigate the mechanics of international trade and CO_2 pollution intensity in two blocs of countries, more and less-developed countries or 'North' and 'South', respectively, by analyzing data from the World Input–Output Database (WIOD). We classify the WIOD countries as South or North according to their GDP per capita relative to the same indicator for the USA, as described in the Database section. The countries within each group (North and South) are diverse in terms of environmental regulations, institutions and economic activity, and our study is silent about such diversity. Furthermore, detailed knowledge of the institutional settings in different countries may offer important insight into how pollution travels from one country to another. Our main point, however, is to analyze general trends in international trade between more and less-developed countries and its implications to the amount of CO_2 emissions embodied in trade flows. The causal relationship between the strength of environmental protection institutions and pollution is an important topic in the economics literature but is beyond the scope of this study.

Our analysis relies on a technique for explicitly identifying and isolating trade relationships between different regions in a multi-sector model, and we calculate the resulting Miyazawa regional trade multipliers (Miyazawa, 1966). We adapt the extensions proposed by Fritz et al. (1998) to estimate the linkages between international trade and the environment on a global scale. In other words, the study explores new ways of identifying emissions based on the regional structure and the sources, both internal and external to a specific region that will generate changes in the spatial structure of emissions.[4]

The evaluation of the linkages between international trade and the environment at a global scale using the Miyazawa approach is in line with the idea of highlighting the role of feedback effects as well as the nature and extent of extra-regional influences on an economy following an additional stimulus (Miyazawa, 1966). Thus, in this approach, we take into account the path of impact generated by an expansion in the regional economy (e.g. North) and its subsequent impact on the rest of the world (e.g. on the South) and back to the original region (North). According to Miller (1966; 1969; 1986) and Miyazawa (1966; 1971), these feedback effects can be important and their neglect would certainly underestimate the overall impact of interregional trade.

Thus, in this study, we use this well-established technique to explore feedback effects in terms of pollution. The technique enables us to perform a mapping and/or decomposing of regional economies, based on a complete scheme of trade flows, the multiplier effect in terms of direct and indirect effects and internal and external linkages/propagation.

In order to stress our contribution, it is important to highlight some similarities and differences between the framework used in this study and other recently published work. Arto and Dietzenbacher (2014), Hoekstra et al. (2016), Malik and Lan (2016) and Malik et al. (2016) have used the structural decomposition analysis (SDA) to decompose the change in GHG emissions. More specifically, these studies have explained changes in emissions

[4] Others have used I–O tables to investigate emissions in different contexts. See, for example, Levinson (2009), Aichele and Felbermayr (2012) and Douglas and Nishioka (2012).

taking into account aspects of carbon efficiency, production recipe, final demand composition, final demand destination, affluence, and population. Although both the Miyazawa technique and SDA rely on input—output tables, they are not mutually exclusive – in fact, they are complementary. Whereas SDA decomposes the change in one variable over time (such as GHG emissions), the Miyazawa framework used in this study takes a look at the feedback effect for each year. In other words, while SDA decomposes the change in GHG emissions between two I–O tables, Miyazawa multipliers allow us to look at the pollution generated by direct and indirect input requirements, as well as internal and external propagation in each I–O table that we have. In addition, since I–O tables are available for a range of years, it is possible to have an intertemporal analysis for both cases, but the Miyazawa approach shows a path for the interregional impacts (e.g. the feedback structure).

Our results suggest that both the North and the South have become less pollution-intensive (technique effect) over the years. Interestingly and in contrast to much of the literature that does not take the interdependence among regions and sectors into consideration, we also find support for the hypothesis that the South has specialized in relatively more pollution-intensive activities (composition effect).[5] Our approach can be extended to the broader literature on factor contents of international trade.[6]

Furthermore, the analysis applied in this study provides strong evidence for the identification and interpretation of emissions linked to the regional economic structure and they suggest a more detrimental impact of trade on the environment and a more important role of the composition effect than previously estimated in much of the empirical literature.[7] To stress our contribution, we refer to the recent article by Levinson (2015). Levinson makes an important contribution to the literature on pollution intensity by analyzing data for the US manufacturing sector and providing a direct estimate of the technique effect. When discussing declining pollution intensities in the US, he concludes that his

> finding should be welcomed by anybody concerned that US regulations might appear to be succeeding, but only by reducing the menu of products available to American consumers or by shifting pollution from the United States to other countries. The results here refute that concern directly.

However, this conclusion cannot be fully endorsed without a model that disentangles the contribution of international trade and of other forces determining the economic structure of different regions to pollution. This is the case because international trade is arguably the channel with the largest potential for international migration of pollution. In fact, we find evidence that less-developed countries have specialized in more pollution-intensive production, even as we observe a global decline in pollution intensity.

This paper is organized into three sections in addition to this introduction. Section 2 describes the method we use; Section 3 describes the database; Section 4 presents and discusses the results and Section 5 concludes.

[5] Most of the studies that use the I–O methodology and focus on environmental impacts embodied in international trade and take into consideration the interdependence among sectors and regions, have showed the South (less developed countries) as a net exporter of emissions and having higher emission intensities than the North (developed countries).

[6] Trefler and Zhu (2010) use a global I–O approach to study factor contents, but not the Miyazawa technique.

[7] See, for example, Antweiler et al. (2001), Frankel and Rose (2005), Douglas and Nishioka (2012) and more recently Levinson (2015).

2. Miyazawa multipliers[8]

For our purposes, Miyazawa's work consists of the definition of multiple regions that interact through trade, and the exploration, from the perspective of a given region, of the internal and external production impacts induced by their interregional trade relationship.[9] Miyazawa's internal and external multipliers are derived from the partition of the Leontief inverse matrix to highlight the impact of internal and external activities on a region's production levels (Okuyama et al., 1999). Here, we closely follow Fritz et al. (1998) and Sonis and Hewings (1993) and refer the interested reader to their work for further details.[10]

Consider the following I–O system with two regions, 1 and 2:

$$\left(\begin{array}{c|c} \mathbf{X}_{11} & \mathbf{X}_{12} \\ \hline \mathbf{X}_{21} & \mathbf{X}_{22} \end{array}\right) = \left(\begin{array}{c|c} \mathbf{Z}_{11} & \mathbf{Z}_{12} \\ \hline \mathbf{Z}_{21} & \mathbf{Z}_{22} \end{array}\right) + \left(\begin{array}{c|c} \mathbf{Y}_{11} & \mathbf{Y}_{12} \\ \hline \mathbf{Y}_{21} & \mathbf{Y}_{22} \end{array}\right), \tag{1}$$

where $\mathbf{Z}_{11}$ and $\mathbf{Z}_{22}$ represent trade flows (intermediate consumption) among sectors within region 1 and 2, respectively; $\mathbf{Z}_{12}$ and $\mathbf{Z}_{21}$ represent trade flows among sectors between regions 1 and 2; $\mathbf{Y}$ stands for final demand; and $\mathbf{X}$ is a matrix with total output of each sector. Like $\mathbf{Z}$, both $\mathbf{Y}$ and $\mathbf{X}$ are partitioned to highlight demand and production for different regions.

From $\mathbf{X}$ and $\mathbf{Z}$, we obtain the matrix of technical coefficients or direct input requirements:[11]

$$\mathbf{A} = \left(\begin{array}{c|c} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \hline \mathbf{A}_{21} & \mathbf{A}_{22} \end{array}\right), \tag{2}$$

where $\mathbf{A}_{11}$ and $\mathbf{A}_{22}$ are matrices of direct input requirements (internal input flows) of the first and second regions, respectively. $\mathbf{A}_{12}$ is the matrix of direct input coefficients purchased (external input flows) by region 2 from region 1 and $\mathbf{A}_{21}$ has a symmetrical interpretation. That is, the matrices on the main diagonal of Equation 2 describe intraregional trade relationships, whereas the off-diagonal matrices describe interregional trade relationships.

To the extent that the Miyazawa framework analyzes interregional trade, the focus is then on the off-diagonal blocks of Equation 2. However, Miyazawa's framework accounts for the fact that interregional trade cannot be viewed independent of the domestic trade linkages (main diagonal blocks).

Using results from the inverse of a partitioned matrix, the Leontief inverse matrix is given by

$$\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1} = \left(\begin{array}{c|c} \mathbf{B}_{11} & \mathbf{B}_{12} \\ \hline \mathbf{B}_{21} & \mathbf{B}_{22} \end{array}\right) = \begin{pmatrix} \boldsymbol{\Delta}_1 & \boldsymbol{\Delta}_1\mathbf{A}_{12}\mathbf{B}_2 \\ \boldsymbol{\Delta}_2\mathbf{A}_{21}\mathbf{B}_1 & \boldsymbol{\Delta}_2 \end{pmatrix}, \tag{3}$$

where

$$\boldsymbol{\Delta}_1 = (\mathbf{I} - \mathbf{A}_{11} - \mathbf{A}_{12}\mathbf{B}_2\mathbf{A}_{21})^{-1};$$

[8] This section is based on Fritz et al. (1998), Sonis and Hewings (1993; 1999) and Okuyama et al. (1999).

[9] The methodological framework was originally proposed by Miyazawa (1966; 1968; 1971) and later extended by Sonis and Hewings (1993; 1995) and Sonis et al. (1997).

[10] Our work differs from that by Fritz and colleagues in that they partitioned an I–O matrix for the Chicago region to study the relationship between clean and dirty sectors, whereas our partition allows us to focus on international-trade-induced pollution.

[11] For more details, see Miller and Blair (2009).

$$\mathbf{\Delta}_2 = (\mathbf{I} - \mathbf{A}_{22} - \mathbf{A}_{21}\mathbf{B}_1\mathbf{A}_{12})^{-1};$$

$$\mathbf{B}_1 = (\mathbf{I} - \mathbf{A}_{11})^{-1};$$

$$\mathbf{B}_2 = (\mathbf{I} - \mathbf{A}_{22})^{-1}.$$

Matrix $\mathbf{B}_1$ contains the internal multipliers for region 1, whereas $\mathbf{\Delta}_1$ is interpreted as the matrix of (external) multipliers for region 1 due to the influence of region 2. The interpretation of matrices $\mathbf{B}_2$ and $\mathbf{\Delta}_2$ is analogous to the interpretation of $\mathbf{B}_1$ and whereas $\mathbf{\Delta}_1$.

Miyazawa's multipliers focus on the lower left submatrix of the matrix in Equation 3 to elicit the impact of region 1's economic activity on region 2's production due to interregional trade (focusing on the upper right submatrix helps us to estimate the opposite relationship). These sub-matrices contain the trade-related production multipliers for the impact of purchases by region 1's activities from region 2's activities.[12] We follow Fritz et al. (1998) and expand this impact analysis to calculate pollution generated in region 2 due to purchases from region 1.[13] To do so, we produce a pollution matrix multiplier by pre-multiplying the lower left submatrix of Equation 3 by a diagonal matrix of region 2's pollution coefficients $\mathbf{R}_2$. Notice that this submatrix contains the multipliers for the impact of purchases by region 1 from region 2. This way, it isolates the impact of international trade on region 2. This approach contrasts to that used in Douglas and Nishioka (2012) based on Trefler and Zhu (2010), who use the entire matrix $\mathbf{B}$ pre-multiplied by $\mathbf{R}_2$, and post-multiplied by trade balances (positive or negative) for all sectors and countries:[14]

$$\mathbf{Pol}_{21} = \mathbf{R}_2[\mathbf{\Delta}_2\mathbf{A}_{21}\mathbf{B}_1]. \tag{4}$$

The multipliers of the matrix $\mathbf{Pol}_{21}$ result from the interaction of three multiplier matrices: $\mathbf{\Delta}_{22}$, $\mathbf{B}_2$ and $\mathbf{B}_1$, with $\mathbf{A}_{21}$. The sources of pollution induced by region 1 sectors' production activities can be unveiled by looking at the column sums of these matrices with respect to the region 2 sectors (Fritz et al., 1998):

(i) $\mathbf{R}_2\mathbf{A}_{21}$ = pollution generated by direct input requirements of region 1;
(ii) $\mathbf{R}_2\mathbf{A}_{21}\mathbf{B}_1$ = pollution caused by direct and indirect input requirements of region 1;
(iii) $\mathbf{R}_2\mathbf{B}_2\mathbf{A}_{21}\mathbf{B}_1$ = pollution caused by internal propagation (direct and indirect production) of region 1 and the induced direct and indirect production of region 2;
(iv) $\mathbf{R}_2\mathbf{\Delta}_{22}\mathbf{B}_2\mathbf{A}_{21}\mathbf{B}_1$ = 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,

where $\mathbf{\Delta}_{22} = (\mathbf{I} - \mathbf{B}_2\mathbf{A}_{21}\mathbf{B}_1\mathbf{A}_{12})^{-1}$. The interpretation of this matrix is as follows: region 1 demands inputs from region 2, which generates direct, indirect and induced production by region 2. These are called the Miyazawa's external multipliers for region 2.

[12] These interregional multipliers account for domestic trade relationships as well (see Fritz et al., 1998).
[13] Fritz and colleagues partitioned an I–O matrix for the Chicago region to study the relationship between clean and dirty sectors.
[14] Also notice that these interregional multipliers account for domestic trade relationships – they contain intra-regional coefficient matrices in $\mathbf{B}_1$ and $\mathbf{\Delta}_2$.

Items (i) and (ii) have standard interpretations from the I–O literature. To better understand (iii), notice that as region 1 demands inputs from region 2, region 2's production increases. This, in turn, causes region 2 to demand inputs from region 1, thus increasing production in region 1. This new increase in production in region 1 generates another round of demands by region 1 for inputs from region 2. This process repeats ad infinitum and converges to the value given by (iii). Finally, (iv) reports the aggregate effect implied by (i), (ii), and (iii). From the definition of $\mathbf{\Delta}_{22}$ and $\mathbf{\Delta}_2$ ($\mathbf{\Delta}_2 = \mathbf{\Delta}_{22}\mathbf{B}_2$), it can be shown that (iv) is the same as the right-hand side of Equation 4 (see Fritz et al., 1998).

For ease of interpretation, we focus on aggregate effects and do not report the impacts associated with individual activities. However, we can obtain interesting economic insights into (i)–(iv) as we look at these individual impact coefficients. These insights will be useful in the construction of the graphs with our main results.[15] To explore these insights, we return to Equation 4 and first notice that the $p_{i_2j_1}$ elements of matrix $\mathbf{Pol}_{21}$ represent the increase in pollution generated by industry i_2 (region 2) as a result of a unit increase in final demand in industry, j_1 (region 1).

The total amount of pollution generated in region 2 by a unit increase in production by activity j_1 from region 1 is the following column multiplier:

$$m_{j_1} = \sum_{i_2} p_{i_2j_1}, \tag{5}$$

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

Following Fritz et al. (1998), industries j_1's column sums in (i), (ii), (iii), and (iv) are termed: $m^1_{j_1}$, $m^2_{j_1}$, $m^3_{j_1}$, and m_{j_1}, respectively. Thus, the following definitions may be employed in the empirical analysis of the impact of region 1's demand for inputs from region 2:

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

Similarly, we can derive and investigate the influence of region 2 in region 1's production.

3. Database

The database used in this study comes from the WIOD. The WIOD is a compatible system of I–O matrices, socioeconomic accounts and environmental accounts, including CO_2 emissions.[16]

[15] Individual industry multipliers are available from the authors upon request.
[16] See Dietzenbacher et al. (2013) and Timmer et al. (2015) for a detailed description of the WIOD database and Timmer (2012) and Genty et al. (2012) for further details on WIOD Socioeconomic Satellite Accounts and WIOD Environmental Satellite Accounts, respectively.

The WIOD input–output tables covering 40 countries (27 countries of the European Union and 13 other selected countries) plus the 'Rest of the World' for the years 1995 through 2011. As approached by Dietzenbacher et al. (2013) and Timmer et al. (2015) the model for the 'Rest of the World' is provided in order to have a complete value-added decomposition of final output. It is important to note that, following the conventions of the System of National Accounts (SNA), these World Input–Output Tables (WIOT) have been constructed by national I–O tables that are connected with each other by bilateral international trade data (Timmer et al., 2015).

The WIOD input–output tables contain data for 35 industries covering the overall economy. As described by Timmer et al. (2015), the range of sectors comprises agriculture, mining, industries (i.e. construction, utilities, 14 manufacturing industries) and services (i.e. telecom, finance, business services, personal services, eight trade, and transport service industries and three public service industries).[17]

Furthermore, it is important to emphasize that the environmental satellite accounts (WIOD environmental accounts) contain CO_2 emissions data for the same range of countries and sectors of I–O tables, but only from 1995 to 2009, which justify our analysis for the period 1995–2009 instead of 1995–2011.

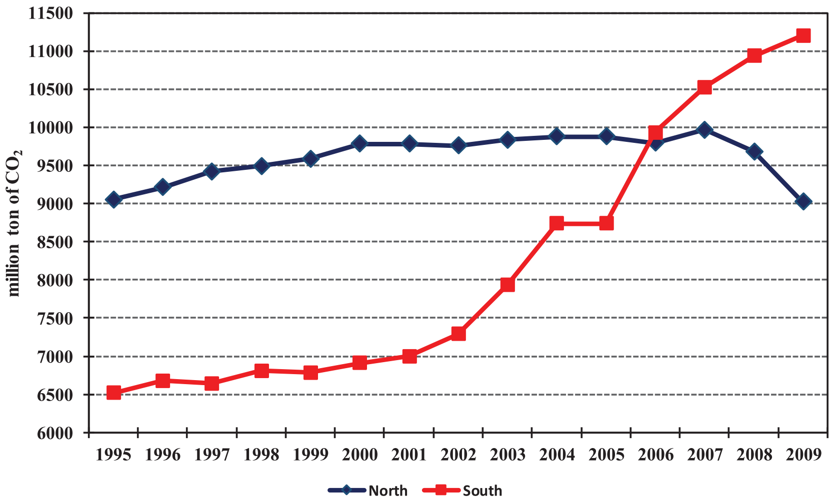
In order to focus on general trends in international trade between more and less-developed countries, we define two regions in this study: the 'South' is composed of countries with a GDP per capita below 30% of the US GDP per capita and the 'North' contains the remaining countries.[18] Our classification differs from World Bank Classification and World Economic Situation and Prospects Classification by the United Nations. Had we used any of these classifications, most of the countries in the WIOD database would fall into the high-income or upper middle income (or developed) categories which does not seem to be a good representation of the economic heterogeneity we observe in terms of international trade, emissions patterns, and economic structure. For example, had we used either the World Bank or World Economic Situation and Prospects Classifications in this study, The United States and Brazil would fall within the same group (high or upper-middle income groups). This would prevent us from understanding trade flows among countries that are very diverse economically but yet fall within the same development classification group. Thus, in order to have a better distribution of the WIOD countries, we considered our own classification as described above. That is, our classification better describes the economic diversity in the database and allows us to more adequately address our research question. It is important to note that 'Rest of the World' is not part of any of these blocs. In other words, this group of countries was properly treated in order to have the final output figures, but it was not part of the analysis. A more disaggregated analysis for countries and sectors is beyond the scope of this study and will be explored in future research.[19]

[17] See Appendix A, Table A1.

[18] See Appendix B, Table B1 to a complete country classification. As we mentioned in the introduction, the countries within each group (North and South) are diverse in terms of their institutional settings, and our study is silent about such diversity. Our main point, however, is to analyze the general trends in international trade between more and less-developed countries and its implications to the amount of CO_2 emissions embodied in trade flows.

[19] If the focus is on the relationship between selected countries or smaller regions (blocs), then the EORA multi-region input–output table (MRIO) database (Lenzen et al. 2012; 2013) may be more appropriate, since it has a finer regional disaggregation and allows us to have more combinations of propagation routes (hierarchy). We notice, however, that, in general, the choice of any database comes with a cost. These databases have strengths and weaknesses which were well-explored by Moran and Wood (2014), Owen et al. (2014), Owen (2017) and others, and it is not immediately obvious which database to choose for many studies.

Figure 1. CO_2 emissions.



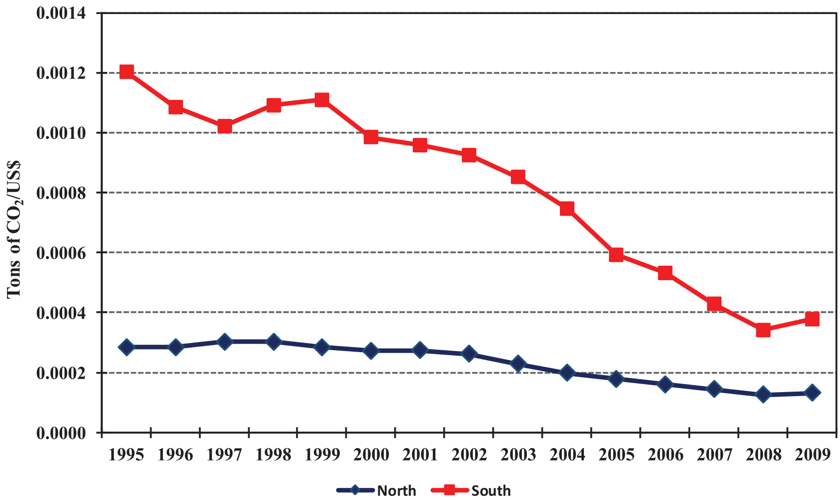
Given the focus of this study, we observe the behavior of the North and the South in terms of CO_2 emissions. On the one hand, Figure 1 indicates that CO_2 emissions in the North increase smoothly until the year 2007, and from that point on, emissions decrease. On other hand, emissions in the South increase for the entire period (1995–2009). Emissions in the South show an exponential pattern with relatively small increments during the early years of our sample (1995–2001), and greater acceleration starting in 2002.

4. Results

Before we delve into the mechanics of international trade and CO_2 emissions in the North and the South, we plot CO_2 emissions intensity of GDP for each region in Figure 2. The data show decreasing emissions per dollar of GDP in both regions, suggesting cleaner production processes worldwide. However, as Figure 1 indicates, this does not translate into a decrease in global CO_2 emissions. Malik and Lan (2016) suggested that almost all world countries have reduced the amount of emissions as a result of high carbon efficiency. However, as analyzed by the authors and similar empirical applications from the recent literature (e.g. Arto and Dietzenbacher 2014; Malik and Lan 2016; Malik et al. 2016; Hoekstra et al. 2016), other factors can be determinants for the change in global CO_2 emissions, such as affluence, population, final demand composition, and final demand destination.[20] The concern with increasing emissions in a globalized world even with improved technologies is what motivates our study on the contribution of international trade to this process.

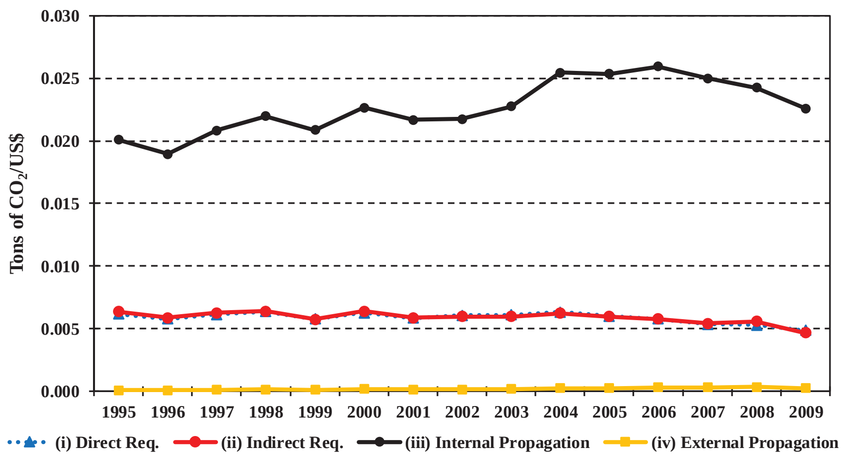
[20] Malik and Lan (2016) and Malik et al. (2016) used the term 'carbon efficiency' to denote technological changes that can lead to changes in the emissions intensity (emissions per unit of output) and the term 'affluence' to indicate changes in per-capita consumption.

Figure 2. Intensity coefficients of CO_2 emissions.



Note: All monetary units were converted to constant 2009 prices using the Chain-Type Price Indexes for Gross Output by industry from the US Bureau of Economic Analysis.

Figure 3. South Miyazawa multipliers.

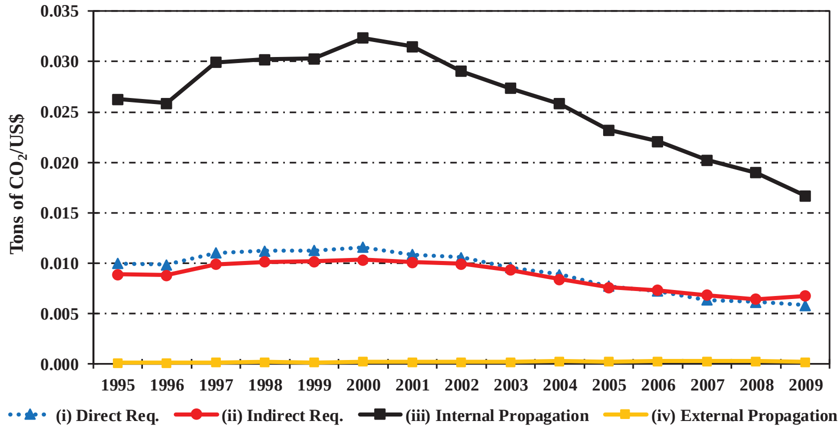


Note: All monetary units were converted to constant 2009 prices using the Chain-Type Price Indexes for Gross Output by industry from the US Bureau of Economic Analysis.

Insight into the relationship between international trade and emissions can be obtained from the Miyazawa multipliers depicted in Figures 3 and 4.[21] Figure 3 shows the trade–pollution multipliers in the South. That is, these are the multipliers describing CO_2

[21] All monetary units were converted to constant 2009 prices using the Chain-Type Price Indexes for Gross Output by Industry from the US Bureau of Economic Analysis. Multipliers are averages of all industry multipliers weighted by the value of production.

Figure 4. North Miyazawa multipliers.



Note: All monetary units were converted to constant 2009 prices using the chain-Type Price Indexes for Gross Output by industry from the US Bureau of Economic Analysis.

emissions from the South per dollar of output due to its exports to the North. Figure 4 shows the equivalent multipliers for the North due to its exports to the South.

To the extent that the Miyazawa multipliers focus on emissions per dollar of output, they control for the scale effect for emissions, assuming no non-linearities that translate larger scales into different emissions per dollar. We can, therefore, focus on insights that pertain to both the composition and technique effects associated with trade and emissions.[22]

The dotted lines plot the direct pollution requirements stemming from international trade (i). The lines superimposing the dotted lines depict the indirect pollution requirements (ii). These suggest cleaner production processes in the North starting in 2000. A similar phenomenon is apparent in the South, although the decline in direct (21%) and indirect (26%) emissions due to trade are smoother than in the North (42% and 24%, respectively) and starts later, in 2004. A simultaneous decline in direct and indirect pollution requirements due to international trade in both regions implies a clean technique effect – migration of polluting activities (composition effect) alone cannot explain a simultaneous decline in these coefficients in both regions. Dasgupta et al. (2002) argue that less emissions-intensive production may be due to progressively stronger environmental institutions in both the developed and developing world and technology transfers from the North to the South.

The fact that both regions are becoming less emissions intensive does not imply, however, that there is no increase in global CO_2 emissions and no composition effect at play. As suggested by Malik and Lan (2016), rising population, affluence (e.g. China) and growth in exports of resources, including oil, minerals, and agricultural commodities (e.g. India, Russia, Brazil, and others), can contribute to increases in CO_2 emissions. Furthermore, as proposed by the authors 'some countries leaking carbon require others to absorb carbon,

[22] The composition effect can result from the migration of production due to changes in relative prices of factors of production or to institutional factors that act as attractors or repellers of pollution-intensive production. Our approach does not allow us to distinguish these drivers of the composition effect, but instead allow us to make inferences about the aggregate composition effect.

allowing the division of the world into leaks and sinks'.[23] That is, dirtier industries might be becoming cleaner, but still moving to regions with lower cost to pollute. This is what the top lines of Figures 3 and 4 seem to suggest.

The top lines depict the internal propagation pollution multiplier due to international trade (iii). The graph for the North depicts a sharp decline starting in the year 2000 (decrease of 36% between 1995 and 2009), whereas the graph for the South shows an upward trend until 2006 and a slow decline afterward (an increase of 12% between 1995 and 2009). Intuitively, the internal propagation multiplier shows subsequent rounds of pollution in a given region, due to its initial exports and continued trade with its international partner. The North has progressively generated less-derived pollution due to its exports to the South, but the opposite was true for most of the series for the South. Since a technique effect seems to have existed in both cases making production less pollution-intensive ((i) and (ii)), the graphs for the internal propagation multiplier (iii) seem to suggest compositional changes with the South specializing in more polluting activities and the North experiencing just the opposite. This compositional effect was strong enough to cause a sharp contrast between the quickly declining total pollution multiplier due to international trade in the North and the delayed and less pronounced decline of the same multiplier in the South (contrast the top lines in Figures 3 and 4). This is in line with the outsourcing results found by Malik and Lan (2016) and Hoekstra et al. (2016).[24] In other words, in line with the idea of pollution havens, where rich countries shift productive processes that are intensive in emissions to developing countries without strict environmental legislation.

Finally, the bottom lines depict the external propagation multiplier (iv). These are pollution coefficients per dollar of output in a given region due to the production multipliers from another region stemming from the initial exports. These play a residual role in the total pollution multipliers and will not be discussed here.

5. Conclusion

This study uses an extension of the regional Miyazawa to perform a mapping and/or decomposing of regional economies, based on a complete scheme of trade flows, the multiplier effect in terms of direct and indirect effects and internal and external linkages/propagation in terms of pollution. The technique enables us to isolate the impact of international trade on CO_2 emissions (international-trade-induced pollution). Our contribution relies on this isolation and, as we mentioned earlier, our results complement other findings from previous studies that have assessed the driving forces for CO_2 emissions based on carbon efficiency, production recipe, final demand composition, final demand destination, affluence, and population (SDA analysis). It complements these recent studies by focusing on feedback effects and the nature and extent of extra-regional influences on an economy in response to an initial stimulus, which produces additional information that can aid the design and implementation of trade-related environmental policies.

[23] Carbon leaking countries have their domestic carbon footprint growing faster than that of the rest of the world, as defined by Malik and Lan (2016).

[24] The term outsourcing has used in different ways by Malik and Lan (2016) and Hoekstra et al. (2016). As clarified by Malik and Lan (2016), they have used the term as imports of carbon embodied in commodities, while Malik and Lan (2016) have used the term as purchase of intermediate and final goods from other countries.

In agreement with much of the existing literature, our results suggest a technique effect making both the North and the South cleaner in their production processes, but in contrast to most studies and in line with Malik and Lan (2016) and Hoekstra et al. (2016), we find evidence of a composition effect implying the concentration of dirtier industries in the less-developed South. This composition phenomenon reinforces the potential carbon leakage concerns associated with unilateral climate policies. However, in contrast to the previous literature, we explore an interregional structure that addresses the prominent role of the important feedback effects in international trade and their consequences to global pollution.

In other words, from our results, which explicitly map pollution intensities (technique effect) and pollution related to regional economic structures (composition effect) over time, it is clear that it is necessary to look more carefully at the impact of international trade on the environment. This conclusion is in line with Hoekstra et al. (2016). They notice that the recent Intergovernmental Panel on Climate Change report emphasizes that it is necessary to cut of GHG emissions in order to avoid significant global temperature increase. However, in contrast with most negotiations and policies that focus on territorial targets in developed countries, the success of global environmental protection actions requires that we look at regional economic structures and trade between developing and developed countries. We add to this debate by highlighting important the role of feedback effects in international trade flows.

In this sense, our result has policy relevance to the extent that carbon emissions outsourcing is bound to undermine international efforts to limit the impacts of climate change. The Paris Agreement that emerged from the XXI conference of the parties within the United Nations Framework Convention reports the parties' goal to keep global average temperature increases to well below 2°C. Furthermore, the agreement envisions climate change mitigation efforts essentially through intended nationally determined contributions, adaptation initiatives, financial mechanisms to support climate-friendly actions and policies, technology development and transfer and capacity building of transparent and efficient climate-related institutions. However, the agreement gives no explicit consideration to the impact of international carbon transfers through international trade. Whereas technology transfers and capacity building could in principle eliminate the concerns with carbon outsourcing (if, for example, all countries used renewable energy only), this is not likely to be the case in the foreseeable future.

Policies and tools to tackle climate change problem need to be properly designed to address the fact that climate change mitigation efforts are in part undermined by trans-frontier pollution through international trade. Certified emission reduction units generated from projects within the realm of flexible mechanisms such as the Clean Development Mechanism or Joint Implementation could be weighted by the amount of carbon leakage they produce through international trade. The framework we present here could provide elements to this weighting process when applied to specific countries and sectors. Pursuing these weights is beyond the scope of this paper and might be a promising avenue of research.

Further research can focus on more disaggregated trade–pollution relationships involving different countries and zooming into different economic sectors. Furthermore, to the extent that we can view CO_2 emissions as a factor of production, our contribution can be extended to the broader literature on factor contents of international trade. That is, the extensions of the Miyazawa contribution that we explore here can be used to estimate the flow and intensity of factors of production embedded in international trade.

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