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Abstract:

This paper investigates the mechanics of international trade and CO2 emissions in two blocs of countries ("North" and "South") by analyzing data from the World Input-Output Database. We use and adapt the Miyazawa technique to estimate the linkages between international trade and the environment at a global scale, 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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JEL Codes: Q56; Q53;F18; C67

International trade and the environment: New evidence on CO_2 emissions.

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Abstract

This paper 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 use and adapt the Miyazawa technique to estimate the linkages between international trade and the environment at a global scale, 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).

Keywords: CO_2 Emissions, International Trade, Input-Output Tables, Miyazawa Multiplier.

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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 and comparative advantages (technique effect), and migration of polluting industries to countries with less stringent environmental policies (composition effect)[1].This debate extends to climate to the extent that trans-frontier pollution can undermine national policies.

We investigate the mechanics of international trade and CO_2 pollution intensity in two blocs of countries (developed or "North" and developing or "South") by analyzing data from the World Input-Output Database (WIOD)[2]. The WIOD is a compatible system of input-output (I-O) matrices and environmental accounts, including CO_2 emissions, for forty countries, thirty-five sectors and for the years 1995 through 2009. We calculate the Miyazawa regional trade multipliers, a technique for explicitly identifying and isolating trade relationships between different regions in a multi-sector model (Miyazawa, 1966). We use and adapt the extensions proposed by Fritz et al. (1998) to estimate the linkages between international trade and the environment at a global scale, a contribution that to our best knowledge has not yet appeared in the literature[3]. 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). Our approach can be extended to the broader literature on factor contents of international trade[4].

[1]See for example, Chichilnisky (1994), Copeland & Taylor (1994) and Antweiler et al. (2001).

[2]See Dietzenbacher et al. (2013) for a detailed description of the WIOD database.

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

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

This paper is organized into three sections in addition to this introduction. Section 2 describes the method we use, section 3 describes our results and section 4 concludes.

2. Miyazawa Multipliers

For our purposes, Miyazawa's work consists of the definition of multiple regions that interact through trade, and the exploration of the internal and external production impacts induced by their interregional trade relationship. Here, we closely follow Fritz et al. (1998) and refer the interested reader to their work and the supplementary material for further details[5].

Consider the following input-output system with two regions, 1 and 2:

$$\begin{pmatrix} \boldsymbol{X_{11}} & \boldsymbol{X_{12}} \\ \boldsymbol{X_{21}} & \boldsymbol{X_{22}} \end{pmatrix} = \begin{pmatrix} \boldsymbol{Z_{11}} & \boldsymbol{Z_{12}} \\ \boldsymbol{Z_{21}} & \boldsymbol{Z_{22}} \end{pmatrix} + \begin{pmatrix} \boldsymbol{Y_{11}} & \boldsymbol{Y_{12}} \\ \boldsymbol{Y_{21}} & \boldsymbol{Y_{22}} \end{pmatrix} \tag{1}$$

where: $\boldsymbol{Z_{ii}}$ represents trade flows among sectors within region i, $\boldsymbol{Z_{ij}}$ represent trade flows among sectors between regions i and j, $\boldsymbol{Y}$ stands for final demand, and $\boldsymbol{X}$ is a matrix with total output of each sector. Like $\boldsymbol{Z}$, both $\boldsymbol{Y}$ and $\boldsymbol{X}$ are portioned to highlight demand and production for different regions.

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

$$\boldsymbol{A} = \begin{pmatrix} \boldsymbol{A_{11}} & \boldsymbol{A_{12}} \\ \boldsymbol{A_{21}} & \boldsymbol{A_{22}} \end{pmatrix} \tag{2}$$

[5] 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.

The Leontief inverse matrix is given by:

$$\boldsymbol{B} = (\boldsymbol{I} - \boldsymbol{A})^{-1} = \begin{pmatrix} \boldsymbol{B_{11}} & \boldsymbol{B_{12}} \\ \boldsymbol{B_{21}} & \boldsymbol{B_{22}} \end{pmatrix} \tag{3}$$

Miyazawa's multipliers focus on the off-diagonal sub-matrices of (3) to elicit the impact of region i's economic activity on region j's production due to interregional trade. These sub-matrices contain the trade-related production multipliers for the impact of purchases by region i's activities from region j's activities[6]. We expand this analysis to pollution generated in region j due to purchases by region i by pre-multiplying the corresponding sub-matrix of (3) by a diagonal matrix of region j's pollution coefficients, $\boldsymbol{R_j}$. This produces an inter-regional trade pollution matrix multiplier:

$$\boldsymbol{Pol_{ji}} = \boldsymbol{R_j B_{ji}} \tag{4}$$

Our approach contrasts to that used in Douglas & Nishioka (2012) based on Trefler & Zhu (2010). They calculate the emissions content of net exports by pre-multiplying the entire matrix B in (3) by $\boldsymbol{R_j}$, and post-multiplying this product by trade balances (positive or negative) for all sectors and countries.

The multipliers of matrix $\boldsymbol{Pol_{ji}}$ result from the interaction between different multiplier matrices, and region j's pollution induced by region i's sectors can be scrutinized by looking at the column sums of these matrices. More specifically, we can calculate the following pollution multipliers for region j due to demand shock in region i:

(i) direct pollution requirements in the total multiplier;

(ii) indirect pollution requirements (due to additional trade within region j stemming from initial production and sales) in the total multiplier;

[6]These inter-regional multipliers account for domestic trade relationships as well (see Fritz et al. (1998).

(iii) internal pollution propagation (direct and indirect effects) of region j in the total multiplier;

(iv) external pollution propagation (direct and indirect effects) of region j in the total multiplier.

Items (i) and (ii) have standard interpretations from the I-O literature. To better understand (iii), notice that as region i demands inputs from region j, region j's production increases. This, in turn, causes region j to demand inputs from region i, which increases production in region i. This new increase region i's output generates another round of demands for inputs from region j. This process repeats ad infinitum and converges to the value given by (iii). Finally, (iv) is the difference between the total pollution multiplier for region j and the accumulated multipliers (i)-(iii).

Similarly, we can derive and investigate the influence of region j in region i's pollution.

3. Results

To focus on general trends in international trade between more and less developed countries, we define two regions in this paper: 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. A disaggregated analysis for countries and sectors is beyond the scope of this paper and will be explored in future research.

Insight into the relationship between international trade and emissions can be obtained from the Miyazawa multipliers depicted in figure 1.[7] The left portion of the figure shows the trade-pollution multipliers in the South. That is, these are the multipliers describing CO_2 emissions from the South per dollar

[7] 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 off all industry multipliers weighted by the value of production

of output due to its exports to the North. The right portion of figure 1 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.

The solid lines plot the direct pollution requirements stemming from international trade (i). The dashed lines superimposing the solid 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 is 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 composition effect at play. That is, dirtier industries might be becoming cleaner, but still moving to regions with lower cost to pollute. This is what the dotted lines above the solid lines of figure 1 seem to suggest. The dotted 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 afterwards (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.

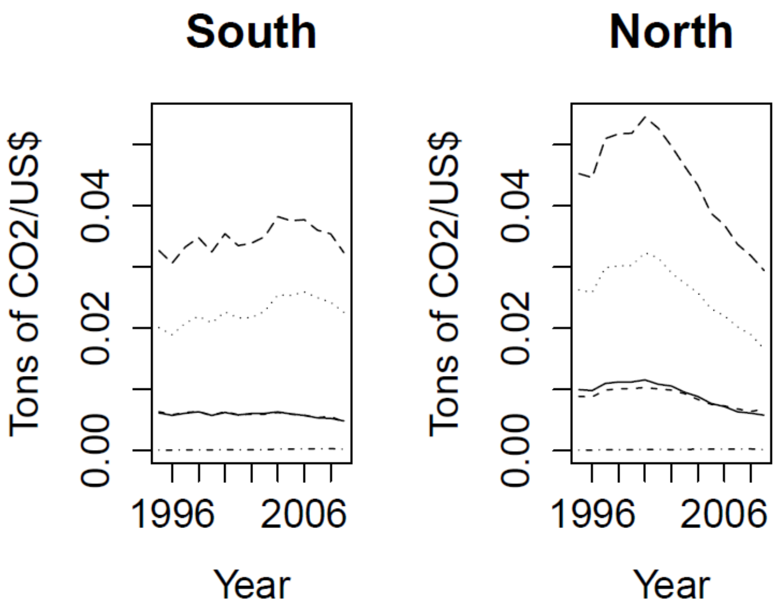

Figure 1: Miyazawa multipliers

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 (top dashed lines in both graphs).

Finally, the bottom dashed lines depict the external propagation multiplier. 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.

4. Conclusion

This paper uses an extension of the regional Miyazawa multipliers to isolate the impact of international trade on CO_2 emissions in different regions. Our results suggest a technique effect making both the North and the South cleaner in their production processes, but in contrast to other studies, we find evidence of a composition effect implying the concentration of dirtier industries in the less developed South. Our contribution lies on the isolation of international-trade-related pollution and can be extended to the literature on factor contents of international trade (CO_2 emissions can be viewed as a factor of production). Further research can focus on the pollution content of specific countries and economic sectors.

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International trade and the environment:
New evidence on CO_2 emissions.
– Appendix –

Appendix A. 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 the interregional trade relationship. 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 level (Okuyama et al., 1999).

Consider the following input-output system with two regions, 1 and 2:

$$\begin{pmatrix} \boldsymbol{X_{11}} & \boldsymbol{X_{12}} \\ \boldsymbol{X_{21}} & \boldsymbol{X_{22}} \end{pmatrix} = \begin{pmatrix} \boldsymbol{Z_{11}} & \boldsymbol{Z_{12}} \\ \boldsymbol{Z_{21}} & \boldsymbol{Z_{22}} \end{pmatrix} + \begin{pmatrix} \boldsymbol{Y_{11}} & \boldsymbol{Y_{12}} \\ \boldsymbol{Y_{21}} & \boldsymbol{Y_{22}} \end{pmatrix} \tag{A.1}$$

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

From $\boldsymbol{X}$ and $\boldsymbol{Z}$, we obtain the matrix of technical coefficients or direct input requirements[9]:

$$\boldsymbol{A} = \begin{pmatrix} \boldsymbol{A_{11}} & \boldsymbol{A_{12}} \\ \boldsymbol{A_{21}} & \boldsymbol{A_{22}} \end{pmatrix} \tag{A.2}$$

where $\boldsymbol{A_{11}}$ and $\boldsymbol{A_{22}}$ are matrices of direct input requirements of the first and second regions, respectively. $\boldsymbol{A_{12}}$ is the matrix of direct input coefficients purchased by region 2 from region 1 and $\boldsymbol{A_{21}}$ has a symmetrical interpretation. That is, the matrices on the main diagonal of (2) describe intra-regional trade

[8]Based on Fritz et al. (1998), Sonis & Hewings (1999), and Okuyama et al. (1999).
[9]For more details see: Miller & Blair (2009).

relationships, whereas the off-diagonal matrices describe inter-regional trade relationships. To the extent that the Miyazawa framework analyzes inter-regional trade, the focus is then on the off-diagonal blocks. However, Miyazawa's framework accounts for the fact that inter-regional 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:

$$\boldsymbol{B} = (\boldsymbol{I} - \boldsymbol{A})^{-1} = \begin{pmatrix} \boldsymbol{B_{11}} & \boldsymbol{B_{12}} \\ \boldsymbol{B_{21}} & \boldsymbol{B_{22}} \end{pmatrix} = \begin{pmatrix} \boldsymbol{\Delta_1} & \boldsymbol{B_1 A_{12} \Delta_2} \\ \boldsymbol{\Delta_2 A_{21} B_1} & \boldsymbol{\Delta_2} \end{pmatrix} \tag{A.3}$$

where:

$$\begin{aligned} \boldsymbol{\Delta_1} &= (\boldsymbol{I} - \boldsymbol{A_{11}} - \boldsymbol{A_{12} B_2 A_{21}})^{-1} \\ \boldsymbol{\Delta_2} &= (\boldsymbol{I} - \boldsymbol{A_{22}} - \boldsymbol{A_{21} B_1 A_{12}})^{-1} \\ \boldsymbol{B_1} &= (\boldsymbol{I} - \boldsymbol{A_{11}})^{-1} \\ \boldsymbol{B_2} &= (\boldsymbol{I} - \boldsymbol{A_{22}})^{-1} \end{aligned}$$

The matrices $\boldsymbol{B_1}$ contain the internal multipliers for region 1, whereas $\boldsymbol{\Delta_1}$ is interpreted as the matrix of (external) multipliers for region 1 due to the influence of region 2. Analogously, we can interpret $\boldsymbol{B_2}$ and $\boldsymbol{\Delta_2}$.

Miyazawa's multipliers focus on the lower left submatrix of matrix (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). We follow Fritz et al. (1998) and expand this impact analysis to pollution generated in region 2 due to purchases from region 1.[10] To do so, the lower left submatrix of (3) is premultiplied by a diagonal matrix of

[10]Fritz and colleagues partitioned an I-O matrix for the Chicago region to study the relationship between clean and dirty sectors.

region 2's pollution coefficients, $\boldsymbol{R_2}$, to produce a pollution matrix multiplier. 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 in region 2. This approach contrasts to that used in Douglas & Nishioka (2012), who use the entire matrix $\boldsymbol{B}$ pre-multiplied by $\boldsymbol{R_2}$, and post-multiplied by trade balances (positive or negative) for all sectors and countries[11]:

$$\boldsymbol{Pol_{21}} = \boldsymbol{R_2}[\boldsymbol{\Delta_2 A_{21} B_1}] \tag{A.4}$$

The multipliers of the matrix $\boldsymbol{Pol_{21}}$ result from the interaction of three multiplier matrices, $\boldsymbol{\Delta_{22}}$, $\boldsymbol{B_2}$ and $\boldsymbol{B_1}$, with $\boldsymbol{A_{21}}$. 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) $\boldsymbol{R_2 A_{21}}$: pollution generated by direct input requirements of region 1;

(ii) $\boldsymbol{R_2 A_{21} B_1}$: pollution caused by direct and indirect input requirements of region 1;

(iii) $\boldsymbol{R_2 B_2 A_{21} B_1}$: pollution caused by internal propagation (direct and indirect production) of region 1 and the induced direct and indirect production of region 2;

(iv) $\boldsymbol{R_2 \Delta_{22} B_2 A_{21} B_1}$: 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.

where $\boldsymbol{\Delta_{11} = (I - B_1 A_{12} B_2 A_{21})^{-1}}$. The interpretation of this matrix is as follows: region 2 demands inputs from region 1, which generates direct, indirect and induced production by region 1. These are called the Miyazawa's

[11]Also notice that these inter-regional multipliers account for domestic trade relationships – they contain intra-regional coefficient matrices in $\boldsymbol{B_1}$ and $\boldsymbol{\Delta_2}$.

external multipliers for region 1.

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 $\boldsymbol{\Delta_{11}}$, 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[12]. To explore these insights we return to equation (4) and first notice that the $p_{i_2 j_1}$ elements of matrix $\boldsymbol{Pol_{21}}$ 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:

$$m_{j_1} = \sum{}_{i_2} p_{i_2 j_1} \tag{A.5}$$

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

Following Fritz et al. (1998), industries j_1's column sums in (i), (ii), (iii) e (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;

[12]Individual industry multipliers are available from the authors upon request.

(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 (direct and indirect effects) of region 2 in the total multiplier;

(iv') $m_{j_1} - m_{j_1}^3$: 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.