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Assessing the role of international trade in global CO_2 emissions: An index decomposition analysis approach

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HIGHLIGHTS

- Modelling the impact of international trade on global/national emissions using IDA.
- Decomposition of production- and consumption-based emission changes.
- Further decomposition of emission balance changes.
- Empirical analysis of global economies' emission changes during 1995–2009.

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ABSTRACT

Trade-related CO_2 emissions are an important component in global emissions. Understanding the role of international trade in emissions is of direct relevance to global and national emission reductions, particularly for major exporters and importers. In the literature, the issue has seldom been studied using index decomposition analysis (IDA), which is a popular tool in assessing growth in national-level CO_2 emissions. In this paper, based on a multi-region I-O analysis, we introduce three inter-linked IDA models to quantify the impacts of trade on the production-based emissions, the consumption-based emissions, and the emission balance of economies, respectively. A salient feature of the models, when applied together, is that they can help to assess the role of trade and the emission performance of economies from multiple perspectives. We discuss the relevant methodological issues as well as the advantages and limitations of the models. We then apply the models to evaluate the impact of international trade on changes in global CO_2 emissions from 1995 to 2009. It is found that while the growing trade volume drove up the total emissions, changes in the emission intensity and goods composition related to trade led to some degree of emission mitigation, particularly after 2005.

1. Introduction

Climate change is a global concern. Growth in energy-related CO_2 emissions has been identified as the main cause of climate change. The growing trend will persist if no substantial efforts on constraining emissions are made [1]. Global initiatives aiming at reducing emissions include the 1992 Kyoto Protocol and the 2015 Paris Climate Agreement. Actions have also been taken at regional and country levels to reduce emissions. An important issue behind climate policies is to identify pathways for emission mitigation. It is grounded largely on understanding changes in energy use and CO_2 emissions.

Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are two analytical techniques that have been widely used to study changes in national-level energy and emissions. They aim at distributing a change in an aggregate to pre-defined factors. They have the same objective but differ in methodological basis and data requirements [2]. From an energy systems analysis viewpoint, the basic form of IDA yields three effects to explain a change in national energy consumption, i.e. sectoral intensity effect, economy structure effect, and total activity effect [3]. The decomposition results present useful insight into national energy and emissions dynamics, and shed lights on a country's energy and emission performances. SDA, built upon input-output (I-O) models, is inherently tied to the study of the inter-industry linkage effect and final demand effect. They can respectively be viewed as an indication of production technology and reflects the impacts of final consumption structure and total final consumption. With multi-

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region I-O tables, SDA can further discriminate the impact of trade on energy/emissions and national economic activities. A review of recent IDA and SDA literature as well as a comparison between the two techniques are given in Wang et al. [2].

Of the two techniques, IDA has been more widely used in policy development and assessment. A main reason is that the results of IDA have strong linkages with policy measures. Examples of such studies are IPCC assessment reports [4,5], Global Tracking Framework of the SE4All program initiated by the United Nations [6], European Environment Agency [7], IEA [8–10], UNIDO [11], Federal Statistical Office of Switzerland [12], Environment Canada [13] and European Union [14]. In comparison SDA has received less attention in energy and emission policy studies in practice. The focus of this study is the technique of IDA and its application to trade-related CO_2 emissions which has traditionally been studied using SDA.

Trade-related CO_2 emissions have become an increasingly important component in global/national emissions. Globalization with supply chains crossing national borders has led to growth in emissions embodied in trade (EET). Xu and Dietzenbacher [15] report that the share of EET in global emissions increased from 24% in 1995 to 33% in 2007. At the country level, the survey by Sato [16] shows that during 1995–2007 the share of EET in China's production-based emissions ranged from 4% to 38% depending on the reported source.[1] The corresponding figures for the United States and Japan were 2–27% and 3–44%, respectively. If international trade continues to grow, economies, particularly major importers and exporters such as China, United States and EU, are likely to see a growing EET. The development may lead to a trade-emission dilemma which needs to be resolved in the context of global emissions reduction. As an example, Liu et al. [17] attempt to identify opportunities to decouple emissions from trade in China.

The varying specialization of economies in the global production system has led to carbon leakage between advanced economies and emerging economies. To more fairly reflect climate responsibilities of countries, consumption-based emission inventory has been advocated as an alternative to the conventional production-based accounting system [18].[2] The consumption-based emission inventory has a number of advantages over the production-based system [19] and has increasingly been used as the baseline to develop various climate policy options, including both trade-related policies (e.g. border carbon adjustments) and domestic policies (e.g. improving production technology and adjusting economy structure) [20,21].[3] For example, Zhang [22] studies the sharing of emission responsibilities among Chinese provinces based on the production-based principle, Barrett et al. [23] study policy issues to control the consumption-based emissions in UK, Mundaca et al. [24] provide a production-based and consumption-based macroeconomic-climate assessment of Sweden's CO_2 emissions, Deloitte [25] assesses Australia's performance in consumption-based emissions and further discusses the climate target setting of the country, and Barrett et al. [26] and Fouré et al. [27] discuss the effectiveness of border carbon tax in the EU context.

Capturing the impact of international trade on global/national emissions has been a widely debated and studied issue. In the literature, the bulk of IDA studies examine the production-based energy use or emissions.[4] Using IDA to study trade-related emissions is a very recent development [2] and the number of reported studies is still very small. A main reason is that data on emissions and economic activity associated with trade is not readily available. The normal practice to gather these data is to adopt the environmentally extended I-O analysis. On the basis of EET calculated using the I-O model, IDA has only recently been applied to study the impact of trade specialization on economies' emission balance in a specific year [17,32–34], and analyze changes in the emissions embodied in bilateral trade [35,36]. Analyzing the impact of trade on the temporal changes in global/national production-based emissions using IDA, however, has not been widely reported. Besides, no IDA study on temporal changes in consumption-based emissions or emission balance has been reported.

This study is an attempt to assess the role of international trade in global/national emissions using IDA. Specifically, based on the multi-region I-O model, we first estimate the production (consumption) by destination (source) as well as emissions embodied in product flows of global economies. The impact of exports on economies' production-based emissions and that of imports on consumption-based emissions are investigated. In addition to the entire national emission inventories, emission balance changes are issues of interest to policymakers since they help to characterize countries' role in international climate negotiation. Quantifying the drivers behind changes in countries' emission balance offers insights on the causes of the trade-emission dilemma [17]. We therefore further study changes in countries' emission balance over time. Three inter-linked IDA models to respectively study changes in production-based emissions, consumption-based emissions, and emission balance with a focus on trade are proposed. For illustration purposes, we apply these models and use the World Input-Output Database to examine global economies' emission changes from 1995 to 2009.

The rest of the paper is organized as follows. Section 2 describes the multi-region I-O approach. Section 3 introduces the three IDA models. Section 4 presents the case study. Section 5 concludes.

2. Basics of multi-region I-O models

The most commonly used technique to estimate consumption-based emissions and EET is the environmentally extended multi-region I-O model. Peters [18] classifies the multi-region I-O methodology into two approaches, namely the emissions embodied in bilateral trade (EEBT) approach and multi-region I-O (MRIO) approach. The difference between them lies in the production technology assumption for trade partners [37]. MRIO approach adopts the domestic production technology for all economies, rendering it superior in EET accounting [38]. Examples using the MRIO approach to compute consumption-based emission inventory and EET include Nansai et al. [39], Wiedmann et al. [40], and Gasim [34]. In the sections that follow we apply the MRIO approach to compute the emission inventories and economic activities of countries.[5]

Assume N economies, each of which is disaggregated into M (i, $j = 1,\ldots,M$) economic sectors, are under consideration. The structure of the MRIO table for the N economies is given in Table 1. The integrated matrix of intermediates $\mathbf{Z}$ is expressed as:

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11},\mathbf{Z}^{12},\ldots,\mathbf{Z}^{1N} \\ \mathbf{Z}^{21},\mathbf{Z}^{22},\ldots,\mathbf{Z}^{2N} \\ \cdots \\ \mathbf{Z}^{N1},\mathbf{Z}^{N2},\ldots,\mathbf{Z}^{NN} \end{bmatrix}$$

where $\mathbf{Z}^{rs}$ is a $M \times M$ matrix denoting the intermediates exported from country r to country s. Define the total output $\mathbf{X} = (\mathbf{X}^{1'},\mathbf{X}^{2'},\ldots,\mathbf{X}^{N'})'$ where $\mathbf{X}^{r'}$ is a $1 \times M$ vector for the total output of country r, and the final demand $\mathbf{Y} = (\mathbf{Y}^{1'},\mathbf{Y}^{2'},\ldots,\mathbf{Y}^{N'})'$ where $\mathbf{Y}^{r'} = \sum_s \mathbf{Y}^{rs'}$ and $\mathbf{Y}^{rs'}$ is a $1 \times M$

[1] Production-based emissions refer to the amount of CO_2 emitted from production activities occurred within a country's territory.

[2] Consumption-based inventory accounts for all the emissions induced by the final demand of a country, regardless of emitters.

[3] Despite its growing popularity in academic research and policy studies, the consumption-based accounting system faces a number of practical challenges in design and implementation. These challenges include the uncertainty in allocating emissions according to consumption activities and the difficulty in implementing consumption-based policy measures in foreign countries. Details about these problems and challenges have been widely reported in the literature. Interested readers can refer to Peters [18].

[4] Examples of decomposition analysis dealing with production-based emissions include Mundaca and Markandya [28], Mundaca et al. [29], Ang et al. [30] and Goh et al. [31].

[5] Although the I-O technique has been widely applied, it should be noted that a number of limitations, including linear modelling of complex economic systems, exist in the approach [41].