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Analysis

A Multi-region Structural Decomposition Analysis of Global CO_2 Emission Intensity

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ABSTRACT

This paper studies changes in global and national CO_2 emission intensities using the multi-region structural decomposition analysis (SDA) technique. Emission intensities such as the ratio of CO_2 emissions to GDP have lately been widely used to characterize national emission performance. Meanwhile the impact of international trade has been found to be important in global emission accounting. It is therefore important to analyze changes in emission intensities by taking trade into consideration. In this study, we first propose two SDA models, one at the global level and the other at the country level, to quantify both the domestic and trade related effects on an intensity indicator. The models are then used to study changes in global and countries' CO_2 emission intensities from 2000 to 2009. The results show that sectoral emission efficiency improvement was the main contributor to the slight decrease in global emission intensity during the period, while international trade marginally hampered improvement of global emission intensity. Comparisons of the performance between emerging economies and advanced economies reveal the importance of production structure and final demand structure in emission intensity reduction. The policy implications of the findings are presented.

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1. Introduction

The rising anthropogenic CO_2 emissions have led to irreversible global climate change, which has had widespread impacts on human and natural systems (IPCC 2014). To mitigate the severe effects caused, international agreements on reducing emissions have been established, and regional/national policies have been implemented to cut emissions. Tracking countries' emission performances and quantifying the driving forces of emissions are of great interest to policymakers since the two issues are important to evaluating effectiveness of policy measures. In the literature, one of the analytical tools that have been applied to assess energy and emission performances is decomposition analysis.

Decomposition analysis, consisting mainly of index decomposition analysis (IDA) and structural decomposition analysis (SDA), is an accounting approach that distributes a change in an energy or emission-related aggregate to predefined factors. The decomposition results obtained offer insights on the driving forces behind the change, based on which policymakers can assess the effectiveness of relevant policy measures. From an energy systems analysis viewpoint, IDA usually measures the effects of total activity level, activity structure and activity intensity on an aggregate. SDA, which is built upon the input-output (I-O) model and deals with the overall economic system, can quantify the impacts of both the production-side and consumption-side factors on an aggregate. IDA and SDA differ in methodological foundation, study scope, factors used in decomposition and policy implications derived (Su and Ang 2012; Wang et al. 2017a). A main advantage of SDA over IDA is that SDA can analyze demand-side effects and the impact of trade. This study focuses on the SDA technique.

In SDA studies, the aggregate decomposed can be a quantity indicator, e.g. total national energy consumption or emissions, or an intensity indicator, e.g. the ratio of national emissions to GDP. In the literature, both forms of indicators have been used to characterize energy or emission performance (Su and Ang 2012; Wang et al. 2017a). They have been used to assess performances with different focuses. The intensity indicator, which is independent of the economic output size, has an efficiency connotation.

A foundation of SDA is I-O models. I-O models can be classified as single-region I-O (SRIO) models and multi-region I-O (MRIO) models, based on which single-region SDA and multi-region SDA can be conducted respectively. A difference between SRIO and MRIO models is that the latter capture the economic linkage between the regions studied in terms of trade and interregional feedback effects (Su and Ang 2011). Arising from the difference between quantity and intensity indicators and that between single and multi-region I-O models, SDA modelling can be classified into four types. They are the SR quantity approach (type I), SR intensity approach (type II), MR quantity approach (type III), and MR intensity approach (type IV).

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Most existing studies belong to type I, i.e. dealing with changes of a single country's energy use or emissions. These studies pinpoint causes behind energy or emission changes in an economy. The methodological and application issues have been extensively studied (Su and Ang 2012; Wang et al. 2017a). Type II studies are not as common but the number is growing. For example, Fan and Xia (2012), Zeng et al. (2014) and Zhang and Lahr (2014) study changes in China's energy intensity, and Zhang (2009), Xia et al. (2015) and Su and Ang (2017) examine China's emission intensity changes. The structural decomposition of a quantity indicator and that of an intensity indicator are fairly different (Su and Ang 2015). Wang et al. (2017b) resolve some methodological issues in multiplicative SDA of an intensity indicator in the single-region context.

Type III studies examine changes in regional or global energy use or emissions. A growing number of studies with a focus on the energy/emissions embodied in trade (EET) have been reported. See, for example, Arto and Dietzenbacher (2014), Malik et al. (2016), de Vries and Ferrarini (2017) and Jiang and Guan (2016) which study changes in global emissions, Lan et al. (2016) which examine changes in global energy footprint, Brizga et al. (2014), Su and Thomson (2016), and Duan and Jiang (2017) which investigate energy and emission changes of a country or region, Xu and Dietzenbacher (2014) which investigate changes in emissions embodied in global trade. The surge in multi-region quantity studies is due to the availability of MRIO databases, e.g. the World Input-Output Database (Timmer et al. 2015), Eora (Lenzen et al. 2013) and GTAP (Narayanan and Walmsley 2008).

With regard to type IV, to the best of our knowledge, no SDA study has so far been reported. A reason is the complexity of modelling intensity indicators using multi-region I-O models. Decomposing an intensity indicator in the multi-region context using SDA, however, is becoming increasingly relevant and potentially useful. Intensity indicators have been widely used as a measure of energy or emission performance. Countries such as China, India, Mexico and Singapore use the emission intensity indicator to define climate targets in the intended nationally determined contributions (INDCs) under the United Nations Framework Convention on Climate Change (UNFCCC). Based on INDCs submissions, countries setting targets using the emission intensity indicator cover nearly 40% of the global emissions in 2014.[1] This underscores the importance of intensity indicators in emission mitigation and climate debate. Arising from this development, type IV SDA studies can be used to help countries to evaluate progress made in emission reduction and identify decarbonization pathways. Since the intensity indicator is scale-free, it can be conveniently applied to compare countries in terms of performance, especially in a multi-country setting.

As is well known, multi-region SDA analysis captures the impacts of trade as well as individual regions' contribution on an aggregate indicator. Globalization has boosted international trade and increased energy and emissions embodied in the trade flow among countries. As a result, EET has become a major component in energy use and emission accounting (Fernández-Amador et al. 2016). It is reported to have accounted for 20% to 35% of global emissions during 2001–2007 (Sato 2014). The ability of multi-region SDA analysis to quantify individual countries' impact on an aggregate offers insights on the spatial dimension, which helps to reveal the opportunities and direction for reducing the global aggregate intensity.

Due to the aforementioned reasons, type IV studies deserve special attention and this study is an attempt to fill the gap.[2] Specifically, structural decomposition of aggregate intensity indicators at the global level is first studied. This is conducted at the finest disaggregation level captured in a MRIO table, i.e. at the sectoral level within countries. The results obtained reveal the impacts of driving forces on the global intensity indicator. Within the multi-region framework, both the domestic and trade-related effects can be quantified. As the global-level decomposition analysis masks intensity indicator changes at the country level, we further study decomposing country-level intensity indicators within the multi-region context. The country-level decomposition analysis distinguishes between domestic and trade-related effects, as in the global decomposition analysis. A complementary step is proposed to link changes in intensities at the country level and global level. Some application issues of the proposed SDA models are discussed. The results of applying the proposed methods to study changes in the global and country emission intensities during 2000–2009 using the World Input-Output Database (WIOD) are presented. The policy implications are discussed.

The rest of the paper is organized as follows. Section 2 proposes SDA methodologies. Section 3 describes the data used in this study. Section 4 presents the empirical results and relevant policy implications. Section 5 concludes.

2. Methodology

Multi-region environmentally extended I-O methodologies consist of two general types, i.e. the emissions embodied in bilateral trade (EEBT) approach and the MRIO approach (Peters 2008). A difference between them is that the MRIO approach fully accounts for the feedback effect embodied in international trade (Andrew et al. 2009). Su and Ang (2011) examine the analytical difference and establish a linkage between the two approaches. Recently, the MRIO approach has increasingly been applied in multi-region I-O analysis and in SDA since it allows trade-related energy/emissions to be computed. A number of recently available multi-region databases further facilitate its application. We adopt the MRIO approach in this study.[3]

2.1. Modelling of Emissions and GDP

Suppose N economies, each of which is further divided into R economic sectors, are under consideration. The relationship between total output and final demand of countries can be established using the MRIO approach, which is described in Appendix A. Combining the I-O model with the emission multiplier yields the formulation of aggregate CO_2 emissions as follows[4]:

$$C = \sum_r C^r = \sum_r \sum_{s,q,i,j} f_i^r H_{ij}^{rs} y_j^{sq} \tag{1}$$

where the superscripts r, s, and q denote countries, the subscripts i and j denote sectors, f_i^r is the emission intensity of sector i in country r defined as the ratio of emissions to value added, H_{ij}^{rs} is the value added requirement coefficient representing the value added needed by sector i in country r to meet one unit of final demand of sector j in country s, y_j^{sq} denotes sector j's final demand that is exported from country s to country q. Similarly, the aggregate GDP calculated from the production approach is formulated as:

$$GDP = \sum_r GDP^r = \sum_r \sum_{s,q,i,j} H_{ij}^{rs} y_j^{sq} \tag{2}$$

[1] Computed based on the World Bank INDC database accessible at: http://spappssecext.worldbank.org/sites/indc/Pages/INDCHome.aspx.

[2] As a note, the issue of changes in aggregate intensity indicators in a multi-region context has been studied in the literature using other techniques, e.g. IDA. Examples of such studies include Voigt et al. (2014) which investigate energy intensities in 40 major economies, Löschel et al. (2015) which study energy intensity in the EU, Pothen and Schymura (2015) which study global material intensity, and Cruz and Dias (2016) which analyze energy and CO_2 intensities in the EU.

[3] The proposed decomposition methodologies in this study can be easily adopted in SDA that is based on the EEBT I-O model.

[4] In SDA studies, the sectoral emission intensity has usually been defined as emissions per unit of total output. However, the definition is inconsistent with the aggregate intensity indicator that has been widely used, i.e. aggregate emissions per GDP (i.e. value added). To resolve the inconsistency, we follow Su and Ang (2015) and Wang et al. (2017b) and use the value added as the activity indicator at the sectoral level. Changes to the conventional intensity definition (i.e. sectoral emissions per total output) can be easily made if necessary.

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