Ecological Economics 101 (2014) 10–20

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

A structural decomposition analysis of the emissions embodied in trade

Yan Xu *, Erik Dietzenbacher

Faculty of Economics and Business, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 17 July 2013
Received in revised form 17 February 2014
Accepted 18 February 2014
Available online 6 March 2014

Keywords:
World Input–output Database
Emissions embodied in trade
Structural decomposition analysis
Global multi-regional input–output model

ABSTRACT

The aim of this study is to quantify the driving forces behind the growth of carbon dioxide emissions embodied in trade (EET). The World Input–output Database is used to estimate EET in 40 countries during 1995–2007 after which a structural decomposition analysis is applied. To avoid biases in the results, we have used the input–output tables in previous year's prices and chained the outcomes. In many developed countries, the growth of emissions embodied in imports is much higher than the growth of emissions embodied in exports. A key reason for this finding is the change in the structure of trade, both in intermediate and in final products. Emerging economies like the BRIC countries have increased their share in production and trade at the expense of developed countries. Producers and consumers in developed countries have shifted towards importing a larger share of products from emerging countries. This is the distinguishing feature that led to an increase of emissions embodied in imports for developed countries and an increase of emissions embodied in exports for emerging countries. These results suggest policy makers to monitor EET more carefully and take the effects of trade on emissions into consideration.

1. Introduction

Significant and due attention has been given recently to the effects of rapid globalization and escalating international trade on environmental impacts at the national level (Wiedmann et al., 2007). Many studies show a growing influence of international trade on national emission trends and find strong regional disparities. For example, Peters et al. (2011a) found that most developed countries have increased their consumption-based emissions (for which consumers in a country are responsible) more than their territorial emissions. This implies that the emissions embodied in imports (EEI) in developed countries have grown more than their emissions embodied in exports (EEE) did. At a global level, growth in international trade thus undermines national efforts to regulate emissions in countries where EEI grows more than EEE. Therefore, effective environmental policies require cooperation of countries all over the world. A better understanding of global emissions embodied in trade (EET) can facilitate developing global environmental policies.

In recognition of trade effects, a number of recent studies have quantified the emissions embodied in global trade (e.g. Davis and Caldeira, 2010). For example, Peters et al. (2011a) found that emissions from the production of traded goods and services have increased from 4.3 Gt CO_2 in 1990 to 7.8 Gt CO_2 in 2008. However, next to quantifying EET it is important to identify and quantify the forces that have caused the changes in EET. For instance, several studies (e.g. Casler and Rose, 1998; de Haan, 2001) found that the emission growth from expansion of household consumption is partially offset by reductions in emissions through efficiency improvements (i.e. lower emission intensities). The question is whether this is also the case for EET and whether the effect differs across countries? Another question is how much changes in EET are affected by changes in international trade? Understanding the driving forces for the transfer of emissions among countries may assist in the design of future climate and environmental policies.

To quantify the driving forces of EET changes, this paper applies a structural decomposition analysis (SDA) within a global multi-regional input–output (GMRIO) framework. To our knowledge, this has not been done before. SDA has been applied to analyze: energy indices for a group of countries using single-region input–output (SRIO) models (Alcántara and Duarte, 2004; De Nooij et al., 2003); EET using a bilateral trade input–output (BTIO) model for China (Du et al., 2011); and CO_2 emissions for a single country (Norway) using a GMRIO model (Yamakawa and Peters, 2011). This study, however, uses a GMRIO model to analyze structural changes of EET all over the world. Our aim is to investigate how and why EET changed in 40 countries (which cover more than 85% of the world's GDP) in the period 1995–2007. In addition, we make comparisons between different geographical regions and examine whether the sources of EET growth differ between developed and developing countries.

The reason for using a GMRIO model is that it provides much more accurate estimates than BTIO or SRIO models. A GMRIO framework allows for tracing all emissions that are associated with final products

* Corresponding author at: University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands. Tel.: +31 62 74 26 837.
E-mail addresses: yan.xu@rug.nl (Y. Xu), h.w.a.dietzenbacher@rug.nl (E. Dietzenbacher).

http://dx.doi.org/10.1016/j.ecolecon.2014.02.015
0921-8009/

back to the country that generated the emissions. This holds, even if the production process lingers through many countries, i.e. in the case of a global supply chain. For instance, an iPhone shipped from China to the US contains components that have been produced in Korea which themselves embody CO_2 emissions generated in the US. BTIO and SRIO models cannot take such complex relations into account and are unable to cover such feedback effects.

There is growing evidence that cross-border supply chains have become more prevalent in the global economy (De Backer and Yamano, 2007). This highlights the importance of taking account of inter-country spillover and feedback effects when estimating embodied CO_2 flows, particularly for countries with much processing trade such as China. Trefler (1995) and Hakura (2001) have shown that it is important to incorporate regional technology differences and full inter-regional connections when predicting trade patterns. When comparing models with and without feedback effects, Peters and Hertwich (2006) find a difference of more than 20% for Norway's net carbon embodied in trade. For the US, Weber and Matthews (2007) also find a difference around 20%. Therefore, full supply chains should be considered when decomposing EET, which is particularly relevant for open economies.

The data requirements in a GMRIO framework are considerably larger than in a BTIO or SRIO model. Moreover, an SDA requires data for at least two points in time and an SDA of emission changes even requires input–output data in constant prices. This is because one of the potential driving forces is the emission intensities, for each industry measured as emissions per dollar of output. Using input–output data in current prices will seriously bias the results. To make this point clear, suppose that a certain industry produces exactly the same amount of goods (in kg) and emits exactly the same amount of CO_2 in 2007 as it did in 1995. The emission intensities thus have remained the same. Because the output prices have—in general—increased over the years due to inflation, the calculated emission coefficients will show a decrease when output values in current prices are used.

GMRIO tables in constant prices, however, do not exist (yet). For our empirical analysis we have used the tables from the recently finished World Input–output Database (WIOD) project. This database includes a time series (1995–2007) of annual GMRIO tables (covering 40 countries) in current prices and in previous year's prices. We use a so-called "chaining technique" (De Haan, 2001) to eliminate the price effects in order to obtain the physical quantity effects. For example, subtracting the output in 1995 in current prices from the output in 1996 in previous year's prices gives the volume growth of output between 1995 and 1996, because goods and services are expressed in 1995 prices. This is done by using the price indices for 1996 (with 1995 = 100). In the same fashion, using outputs expressed in 1996 prices provides the volume growth between 1996 and 1997. Adding both volume growths then gives the volume change between 1995 and 1997.

Tables in constant prices express all data in prices of the same base year (1995, in this example) whereas the chaining technique uses annually changing base years. To obtain the values in constant prices, commonly Laspeyres and Fisher price indices (ISWGNA, 1994) are used. They calculate the price of a basket of goods in two years where the composition of the basket is the composition in the base year (Eurostat, 2002). Because data in constant prices use the same base year, their accuracy generally decreases as one moves further away from the base year (Eurostat, 2001). Using a series of annual tables in previous year's prices implies that the basket of goods (which is used to determine the price index) is updated every year. The chaining technique thus avoids an accumulation of biases.

In this paper we will decompose the changes in EEI and EEE between 1995 and 2007. Three main driving forces are involved in the decomposition analysis: changes in emission intensities, changes in production technology and changes in demand for final products. The changes in the trade structure are included by splitting changes in production technology into changes in domestic inputs and changes in imported inputs, and by splitting changes in final demands into changes in demand for domestic final products and imported final products. After discussing the background for this study in Section 2, the details of our analytic approach are described in Section 3 (i.e. the estimation of EET and the chaining technique applied to SDA). Section 4 discusses the data we have used, and Section 5 presents and analyzes the results from the SDA. Finally, conclusions are presented in Section 6.

2. Background

With the growing concern about climate change and related energy and environmental issues, input–output analysis has become an important tool in environmental policy analysis. Estimating emissions embodied in trade and analyzing emission indicators with structural decomposition analyses are two popular areas in environmental input–output (IO) analysis. With respect to the first area, EET studies enable us to understand: the embodied emission flows through international trade; the net bilateral emission transfers via trade from one country or region to another, and the resulting "carbon leakage"; the differences between territorial-based and consumption-based emissions; and a country's responsibility for global emissions which underlies its carbon footprint. With respect to the second area, SDA studies enable us to understand the driving forces behind the historical changes of an aggregate indicator, such as CO_2 emissions, EET, or energy consumption. The effect brought about by each of the driving forces can be quantified and evaluated.

In a comprehensive survey of the empirical literature on embodied carbon in trade, Sato (2012) reports that large and growing volumes of EET have been found. For example, in 2004 about 4 to 6 Gt of CO_2 was embodied in global trade, which equals 15–25% of the annual global emissions. In 2008, however, this figure has increased to 7.8 Gt (Peters et al., 2011a) or 28% of global emissions. This is in line with ongoing globalization and international integration of supply chains in the past decade. The world has seen a rapid growth in global merchandise trade by 460% in value terms between 1990 and 2008. During the same period, population and global GDP grew by 21% and 64%, respectively (Heston et al., 2011).

Other reviews have focused on the literature on methodological issues (e.g. Hertwich and Peters, 2009; Peters and Solli, 2010; Wiedmann, 2009; Wiedmann et al., 2011). Three approaches in environmentally extended input–output analysis have been used to calculate EET: the single-region input–output (SRIO) model; the bilateral trade input–output (BTIO) model; and the global multi-regional input–output (GMRIO) model. The distinctions between the three models are in the way in which imported intermediate goods are treated and in the assumptions that are made about technology and emissions.

The GMRIO models combine domestic input coefficient matrices with import matrices for multiple countries into one large coefficient matrix. They capture the full global supply chain and are able to cover feedback effects. Several reviews have concluded that GMRIO models are the most appropriate approach for EET quantification at country level (Peters and Solli, 2010; Rodrigues et al., 2010). It should be stressed, however, that GMRIO models are quite demanding in terms of data requirements. Because not all data are available, GMRIO models rest to some extent on estimates. Also, not all available data are of the same quality which leads to several types of uncertainties, e.g. in international trade data, emission data, aggregation, currency conversion, and the rest of the world (Andrew et al., 2009; Lenzen et al., 2004, 2010; Rodrigues and Domingos, 2007; Weber, 2008; Wiedmann et al., 2010; Wilting, 2012).

Recently, several MRIO datasets with a global coverage and environmental extensions have been developed. They include: Eora (Lenzen et al., 2012, 2013); EXIOBASE (Tukker et al., 2009, 2013); GTAP-MRIO (Andrew and Peters, 2013; Peters et al., 2011b); WIOD (Dietzenbacher et al., 2013); OECD database (Nakano et al., 2009); and GRAM (Bruckner et al., 2012; Wiebe et al., 2012). These datasets are for