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Constructing long-term (1948–2011) consumption-based emissions inventories

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ABSTRACT

Accompanying the boom in the global economy, CO_2 emissions have soared over the past several decades, with the developing world exhibiting higher emission growth rates than the developed world. Emissions transfers between regions, which represent a significant fraction of total emissions, are assumed to be a primary factor contributing to this difference. It is important to understand these transfer figures and the resulting consumption-based emissions in order to evaluate the emissions drivers and establish climate policies. Existing studies, however, have merely estimated figures over a 20 years span (post-1990) using a traditional input–output analysis (IOA) framework. To broaden the data coverage (to pre-1990) of these transfer figures and to further analyze their impacts on total emissions in the long term, a new model called the Long-term Consumption-based Accounting model (LCBA), which is directly based on statistics, is developed to span the period from 1948 to 2011. The results are consistent with the magnitudes and trends of existing studies over the validation (post-1990) period. We use Monte Carlo methods to calculate upper and lower bounds on the LCBA for each country and year, and find that 3 existing time series are almost fully included within these boundaries from 1990. Furthermore, the LCBA model is succinct enough to be easily expanded for future GHG estimations or to analyze other ecological footprints related to "the flow of materials". It can be assumed that the soaring emissions transfers will seriously jeopardize the current climate policies such as Kyoto Protocol. The Durban Platform for Enhanced Action (ADP) under which all parties are legally bound will require a consumption-based accounting method together with the territorial one in order to achieve an equitable agreement. However, more researches are still needed to facilitate the use of these figures to better support decision making.

1. Introduction

Accompanying the surge of international trade and the booming global economy is a heavy burden of GHGs that jeopardizes the natural system. International trade-links (global supply chains) reveal that geographical separation between production and consumption can be useful for companies to gain maximum profit. Related concepts, such as "ecological footprints" (Turner et al., 2007), "emissions embodied in trade" (Kanemoto et al., 2011; Peters et al., 2012a), and "consumption-based emissions" (Peters, 2008; Davis and Caldeira, 2010; Davis et al., 2011; Vetőné Mózner, 2013) have been widely studied over the past decade. Researchers have claimed that a portion of the production-based emissions in developing and emerging economies has been exported to developed regions as consumption, which ignites concerns about the efficiency of current climate policies and challenges the traditional carbon accounting system by substituting a production view with a consumption one. A production view or territorial view merely accounts for emissions that are produced within sovereign territories, while a consumption view also encompasses emissions conveyed through international trade.

In order to assign the GHGs emission responsibility to each agent or region, one need to know its contribution to this phenomenon in accordance with the benefits it receive through historical economic activities (Shue, 1999). Currently, several indicators have been used to quantify this (Gallego and Lenzen, 2005; Lenzen et al., 2007; Lenzen, 2008; Lenzen and Murray,

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2010; Rodrigues et al., 2006; Rodrigues and Domingos, 2008a). Production-based indicator is emissions directly generated through production processes. Consumption-based indicator is emissions originated upstream along the supply chain to deliver goods and services to final demand (Kanemoto et al., 2011; Lenzen and Murray, 2010; Peters et al., 2012a); Income-based indicator accounts for all emissions generated downstream along the supply chain due to the supply of primary factors of production (Marques et al., 2012, 2013); Shared indicators are trade-off of the above indicators (Gallego and Lenzen, 2005; Lenzen et al., 2007; Lenzen, 2008; Rodrigues et al., 2006; Rodrigues and Domingos, 2008a,b). Although there are empirical studies on the global (Marques et al., 2012, 2013; Rodrigues et al., 2010), regional (Lenzen and Murray, 2010; Zhang, 2010, 2013) and corporate level (Petherick, 2012; Schücking et al., 2011) using these indicators, there exists little agreement about how to share the burden. Preferred suggestion is to use specific indicators for certain policy discussions (Andrew and Forgie, 2008; Rodrigues and Domingos, 2008a). These disputes have laid down a foundation for clarifying historical responsibilities and proposed a beneficial guide for future mitigation policies, especially for the Durban Platform for Enhanced Action (ADP) under which all partners will be restricted by one legally binding commitment. And since "common but differentiated responsibility" (UNFCCC, 1992) should still be held as a fundamental belief under the ADP scheme, long-term datasets in production-based view, consumption-based view or shared view are further needed to clarify responsibilities and to guide policy making. In this paper, we mainly focus on consumption-based view.

Most of existing studies on consumption-based emissions are initiated based on theoretical frameworks of input–output models (Miller and Blair, 2009). Research has evolved from focusing on one country and its major partners over specific years to one country over time, then to various countries over specific years and finally to global analyses over time (Davis and Caldeira, 2010). Various studies on consumption-based accounting have recently been implemented at a multi-regional (global) scale (Peters and Hertwich, 2004; Lenzen et al., 2004; Peters et al., 2011a) using MRIO (Multi-regional Input–output model) or EEBT (Multi-regional Input–output model based on emissions embodied in trade) techniques, or at a national scale using SRIO (Single-regional input–output model) methods (Wiedmann et al., 2007, 2009). Multi-regional models are commonly used because they are consistent with global climate policies; however, most of them merely focus on specific years (Ahmad and Wyckoff, 2003; Peters and Hertwich, 2008; Nakano et al., 2009; Davis and Caldeira, 2010). This is because such studies are usually limited by data availability (Miller and Blair, 2009) which make it hard to track changes over time using input–output frameworks. Currently, only 3 studies partially transcend this limitation and enable time-series analyses at a global scale over 1990–2010 (Lenzen et al., 2012; Peters et al., 2011b; Wiebe et al., 2012). Based on a modified TSTRD (an algorithm to achieve long time series with trade data) method (Peters et al., 2012b), the Global Carbon Program (GCP) nowadays is able to offer preliminary estimates of consumption-based emissions successively, with only a one-year delay. Nevertheless, when the question — "How can one backdate consumption-based data before 1990?" arises, there exists no answer due to the data constraints in the current calculating framework. Since long term historical data in the consumption view is crucial for the development of future climate policies and international negotiations under the rule of "common but differentiated responsibility", theories and methods for historical estimation are further needed. This study set up a clear and succinct algorithm for estimating historical consumption-based emissions and incorporated data going back to 1948 from 164 countries (see Appendix A).

2. Materials and methods

2.1. Accounting method

Territorial emissions inventories which are commonly used in climate change researches and negotiations are emissions taking place within national territory and offshore areas over which the country has jurisdiction (IPCC, 2006). By combining these inventories with international trade data, consumption-based emissions inventories are derived from adding emissions associated with imports and subtracting emissions associated with exports. However, in contrast to the traditional consumption-based accounting method using Input–output models (e.g. MRIO & EEBT) which are limited by data availability, our study set up a new framework using Equations (1):

$$F_{\mathrm{Cr}}(r,i) = F_{\mathrm{Pr}}(r,i) + \mathrm{COEF}_{\mathrm{im}}(i)^{*}\mathrm{Imports}(r,i) - \mathrm{COEF}(r,i)^{*}\mathrm{Exports}(r,i) \qquad \text{s.t.} \quad \sum_{r} F_{\mathrm{Cr}}(r,i) = \sum_{r} F_{\mathrm{Pr}}(r,i) \tag{1}$$

where $F_{\mathrm{Cr}}(r,i)$ and $F_{\mathrm{Pr}}(r,i)$ represent the consumption-based and production-based emissions for region *r* in year *i*, respectively. Imports(*r*,*i*) and Exports(*r*,*i*) are the annual trade of goods and services from each region *r*. COEF(*r*,*i*) is the "production intensity" estimated (CO_2 emissions per unit of "Gross Productive Output") for region *r* in year *i*. Here, "Gross Productive Output" means GDP plus imports and subtracts "imported elements" which will be discussed later. $\mathrm{COEF}_{\mathrm{im}}(i)$ means "importation intensity" which is calculated based on all of the "production intensities" estimated for year *i*. We use a global average value to represent the "importation intensity" which is the same for all countries because we do lack detailed imports flow data among countries. The constraints in equation (1) reveal that total production-based emissions in a specific year must equal those of the consumption-based emissions in the same year over all 164 countries.

There are 2 crucial points in LCBA model. The first is to estimate the "production intensities" for each of the 164 countries over 64 years. The second is to calculate the "importation intensities" for each year based on these data. In contrast to the popular concept "emission intensity," which merely provides estimates of CO_2 emissions per GDP, COEF(*r*,*i*) generates a more accurate concept — "production intensity" — and estimates its intervals for each region and each year.

When calculating GDP using an expenditure approach, GDP is a sum of Consumption (*C*), Investment (*I*), Government Spending (*G*) and Net Exports ($X - M$) as expressed in Equation (2):

$$\mathrm{GDP} = C + I + G + (X - M) \tag{2}$$

In the input–output model, *C*, *I*, *G*, *X* (exports) and *M* (imports) can be treated as basic elements in final use. Apart from *X* and *M*, all of the other 3 items are satisfied by both the domestic elements (C_1, I_1 and G_1) and the imported elements (C_2, I_2 and G_2), as shown in Equation (3):

$$\mathrm{GDP} = (C_1 + I_1 + G_1) + (C_2 + I_2 + G_2) + (X - M) \tag{3}$$

Furthermore, the imports (*M*) are usually consumed for both intermediate use and final use, which means that *M* is larger than ($C_2 + I_2 + G_2$). Since production-based emissions should only account for emissions from "Gross Productive Output" (($C_1 + I_1 + G_1 + X$)), which excludes imports (*M*) and imported elements (C_2, I_2 and G_2) from the GDP, it is the CO_2 emissions per "Gross Productive Output" that should be treated as the accurate meaning of "emission intensity". However, "Gross Productive Output" can only be estimated because it is hard to separate C_2, I_2