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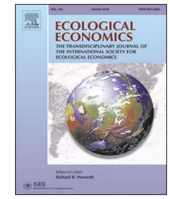

Analysis

Environmental Footprints of Agriculture Embodied in International Trade: Sensitivity of Harvested Area Footprint of Chinese Exports

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ABSTRACT

Consumption-based accounting seeks to link a population's lifestyles to their environmental impact. Input-output analysis (IOA) serves well in this approach as it covers all traded products, their full supply chains and explicitly delineates final consumption. However, using IOA comes at the expense of precision due to aggregation error. There has been a recent discussion on the plausibility of IOA results of agricultural pressures. We look at the harvested area footprint of Chinese exports, open the black box of the results of IOA and provide a detailed composition of the footprint. This helps to understand whether its size is a result of the poor precision of IOA methods, or whether it is based on plausible production patterns of the exported products.

We hybridize the EXIOBASE database, identify the most important exported products, apply structural path analysis in order to identify the most important production nodes in their production paths and apply a sensitivity analysis over the model.

We show that the results of the hybrid MRIO method are generally robust to assumptions. Our results indicate that while the uncertainty of the sign of net trade footprint can be high, the uncertainty of national environmental footprint accounts is low.

1. Introduction

Environmentally-extended multi-regional input-output (EE-MRIO) analysis offers a means to understand the broad system of socio-economic metabolism. It can be used to trace the drivers for environmental pressure through the global economy and to allocate environmental pressures to final consumers, covering the complex supply chains of international trade. It has been applied in many environmental applications, such as emissions of greenhouse gases (Peters et al., 2011), land use (Weinzettel et al., 2013), water use (Steen-Olsen et al., 2012), biodiversity loss (Lenzen et al., 2012), etc. However, EE-MRIO is not a panacea, as there are many assumptions, uncertainties and limitations included in its use (Miller and Blair, 2009). Furthermore, it is a top-down approach that while covering the whole economy, necessarily aggregates similar products into product groups that may introduce *aggregation error* when products differ in certain properties. The application of EE-MRIO to specific sectorial or trade related questions further accentuates aggregation errors.

There has been a recent discussion on the precision and accuracy of MRIO based results for national footprints with environmental pressures primarily in the agricultural sector (e.g. land, water, biodiversity footprints). Kastner et al. (2014) criticise MRIO models as presenting counter-intuitive results in comparison to physical trade studies. In their example, physical trade matrices generally show China to be a net importer of “embodied” cropland, whereas MRIO results generally show China to be a net exporter. This was also visible in earlier work by Peters et al. (2012), Fig. 12. Weinzettel et al. (2014) focus on an analysis of the quantitative differences between input-output and physical trade methods, Schaffartzik et al. (2015) focus on the discussion of conceptual differences. While Schaffartzik et al. argue that “*these two types of approaches may produce diametrically opposed results for the land requirements associated with one country's final demand*” (p. 704), Weinzettel et al. show that this argumentation is true for net trade only, not for the national footprint. Hubacek and Feng (2016) argue that each method is suitable for different purpose, but the discussion is limited to aggregate results and a description of the conceptual differences. Moran et al. (2016) examined the suitability of MRIO for a detailed analysis of embodied biodiversity impacts on a product level and concluded that MRIO is suitable to identify the hotspots for environmental footprints within the socio-economic metabolism, which helps to focus further

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research.

Our current paper advances this discussion on agricultural footprints as we analyze the results from an EE-MRIO approach in the case of harvested area footprint of China. We open the black box of the results of IOA and provide a detailed composition of the footprint. This helps to understand whether its size is a result of the poor precision of IOA methods, or whether it is based on plausible production patterns of the exported products. We (a) look at the current situation of Chinese trade and at the use of agricultural crops in the Chinese economy, (b) provide a sensitivity analysis of the results, and (c) provide a detailed analysis of the footprint of Chinese exports. We focus on Chinese exports as China due to the recent discussion in the literature (Hubacek and Feng, 2016; Kastner et al., 2014) and because China is a large exporter of manufactured products, which generally involve complex production chains in which the errors can propagate and distort the final results. This work is relevant to all environmental footprints originating mainly from agriculture.

2. Materials and Methods

2.1. Definitions

One key concept that is sometimes misconstrued is the notion of "embodiment". The embodied impact is the impact caused in the supply chain of a product – it is often used for emissions, and includes impacts resulting from the production process of a good or service, e.g. CO_2 emitted in electricity generation is said to be "embodied" in the electricity used to power a light. The embodied impact can be calculated at different points along a production chain. Generally, the aim of calculating embodied impacts is to stop burden shifting (Wood and Steen-Olsen, 2013) – hiding environmental impacts up the supply chain. There is a synonymy to functional units in life-cycle assessment – in economy-wide approaches; the functionality is often the livelihood of a population in a certain year (potentially denoted by beyond-GDP indicators such as "happy life years"). An "embodied" approach is central to and synonymous with all "footprint" type analyses. It has a clear difference to material and substance flow type analysis, which look at the material content of an element in a product, such as the aluminium in a car (Nakajima et al., 2011). The concept of embodied impact has found to be useful in conceptualising our indirect reliance on the natural systems that support us – especially as consumers get more disconnected from basic means of production.

However, an "embodied impact" is not a tangible quantity. It implies some sort of allocation to drivers or notion of "responsibility" of a tangible emission or land use to the products or functions that are outputs of the product system. This allocation can be done by different methods (Loiseau et al., 2012; Majeau-Bettez et al., 2014), and based on different characteristics (Ardente and Cellura, 2012; Pelletier et al., 2014; Weinzettel, 2012). This latter point introduces certain problems for different fields – while allocation via physical relationships is often accepted (allocate the impact of the cow to the demand for leather shoes), those via non-physical relationships is less accepted, e.g. the activities of a hired marketing company to promote a car are seldom included in a conventional process life cycle assessment of a car. As a result, researchers have approached the problem by disaggregating product groups to groups with similar characteristics (Wood, 2011), using mixed unit-tables to choose a unit to best represent product characteristics (Weisz and Duchin, 2006), or to create hybrid tables where part of the allocation is done via a physical satellite system, and part is done via the MRIO (Weinzettel et al., 2014). There is no observation of an embodied impact, just various ways to increase precision towards a meaningful capture of burden shifting. In the following, we introduce some of the methodological technicalities of such hybridisation.

2.2. Methods - Hybrid MRIO Method

MRIO approaches cover the system boundary of the economy – any valued good and service is included (Weinzettel et al., 2014). As the data requirements of describing industrial production (**S** for environmental or other factor inputs and **L** for inputs of processed goods and services) are substantial, the tractability of data becomes more difficult, and products are always aggregated into broader product groups.

Earlier work of Weinzettel et al. (2014) showed that standard MRIO may not be suitable for accounting of environmental footprints of agriculture due to low product resolution of the existing datasets and that more effort should be directed towards primary crops and their processing, possibly using a hybrid MRIO framework as proposed by Ewing et al. (2012).

For exploring the supply chain impacts of exported goods presented in detail below, Ewing et al. (2012) proposed a hybrid EE-MRIO model in which primary crops are allocated to the economic sector of the MRIO table according to their first use and not production.

The footprint **E** of a final demand **y** is calculated through the following equation:

$$\mathbf{E} = \mathbf{C} * \mathbf{S_p} * \mathbf{L} * \mathbf{y} + \mathbf{C} * \mathbf{y_p} \quad (1)$$

where $\mathbf{S}_\mathrm{p}$ is the physical use matrix of primary crops by economic sectors per unit of sector output (tonnes per euro), **C** is the characterisation matrix to convert the primary crops measure in tonnes into specific footprints – in our case into harvested area, therefore, **C** in our case is the reciprocal of a yield as reported by FAOSTAT (FAO, 2015), $\mathbf{y_p}$ is a vector of primary crops consumed directly by final demand. Of note is that compared to Eqs. (3)–(5), $\mathbf{S}_\mathrm{p}$ contains actual agricultural products, and not the environmental pressure (whether it be land area or mass of harvested products) of the products. $\mathbf{S}_\mathrm{p}$ also only contains primary crops further transformed in the economy, and not processed crops or livestock; $\mathbf{y_p}$ contains the direct consumption of crops. Hence, the hybridisation occurs by splitting $\mathbf{y_p}$ from total crops, and handling them exogenous to the IO model. For a calculation of international trade it is suitable to split the impacts per unit into direct footprint, i.e. the harvested area of primary crops $\boldsymbol{Q}^{dir}$ and indirect impact per unit $\boldsymbol{Q}^{ind}$ of all products (non-primary crops do not have direct footprint):

$$\boldsymbol{Q}^{ind} = \mathbf{C}^* \, \mathbf{S_p}^* \mathbf{L} \quad (2)$$

$$\boldsymbol{Q}^{dir} = \mathbf{C} \quad (3)$$

Then embodied impacts in exports $E_{h,r}{}^{exp}$ and imports $E_{h,s}{}^{imp}$ are calculated as a sum of indirect impacts calculated through the economic processing (subscript m) and the direct impacts calculated through the direct physical trade (subscript p):

$$E_{h,r}^{exp} = Q_{m,r}^{ind*} \sum_s B_{m,r,s} + Q_{p,r}^{dir*} \sum_s B_{p,r,s} \quad (4)$$

$$E_{h,s}^{imp} = \sum_r Q_{m,r}^{ind*} B_{m,r,s} + \sum_r Q_{p,r}^{dir*} B_{p,r,s} \quad (5)$$

2.3. Integrating Commodity Balance for Primary Crops

The hybrid MRIO applied here is based on a product-by-product MRIO table distinguishing 200 products compiled under the industry technology assumption and based on the EXIOBASE (v2.2, year 2007) database (Tukker et al., 2013; Wood et al., 2014; Wood et al., 2015). It treats the international trade based on country-by-country international trade data and the domestic first use of primary crop products, such as wheat, maize, etc. as extensions based on commodity balance sheets of the FAOSTAT database. The primary crop products produced within each country are allocated to their first users globally.

First, the total country consumption of each crop from each country is estimated based on FAOSTAT bilateral trade data and production