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Comparing apples and oranges: Some confusion about using and interpreting physical trade matrices versus multi-regional input–output analysis

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ABSTRACT

The questions of how to account for upstream land requirements is highly relevant for assigning responsibility for global land use. Two approaches, physical trade flow analysis and multi-regional input–output analysis have been frequently used for land accounting of international trade leading to diametrically opposed results for countries such as China. In this study, we investigate and explain the differences by comparing the estimates of cropland embodied in international trade for China from studies using physical trade flows (PTF) and multi-regional input–output (MRIO) analysis and provide a step-wise calculation to explain the gap between estimates from these different approaches and their interpretation. Our results show that the gap between PTF and MRIO is largely due to the system boundary selection and truncation errors from the boundary cut-off. These two approaches should be used for different research purposes. If focusing on the flows of a particular product, in particular primary products such as rice, wheat or other grains, among countries the higher level of detail of physical flow model is more suited. Whereas when accounting for the total embodied land in trade and consumption-based land use by recipient countries to analyze drivers of land use, MRIO is more suitable for tracking entire global supply chains.

1. Introduction

Multi-region input–output analysis (MRIO) has become a widely used tool to establish consumption based accounts and to analyze complex global supply chains (e.g., Davis and Caldeira, 2010; Lenzen et al., 2013a, 2012; Peters et al., 2011; Prell et al., 2014; Tukker et al., 2014; Wiedmann, 2009; Wiedmann et al., 2015), and as a tool to connect distal (teleconnected or telecoupled) natural and human systems (Hubacek et al., 2014; Liu et al., 2013; Yu et al., 2013). This popularity of the MRIO approach has been driven by the availability of a number of global MRIO databases that have recently come online and greatly facilitate global analyses (Tukker and Dietzenbacher, 2013). But different MRIO databases can substantially differ with regards to the number of countries they include, their sectoral detail and temporal resolution. For example, the GTAP (Global Trade Analysis Project) database contains 57 economic sectors and 140 countries/regions in its latest version 9 for the years 2004, 2007, and 2011. GTAP based MRIO data has the most comprehensive agricultural sectors (8 crops, 4 livestock sectors, 1 forestry, and 1 fishing) compared with other MRIO databases (Andrew and Peters, 2013). However, by the time of publication the data is usually about 5 years old, and the latest available year is 2011. The World Input–Output Database (WIOD) provides 35 economic sectors (with only 1 agriculture sector) and 40 countries and 1 Rest of the World region covering the years 1995–2011. The WIOD database focuses mainly on EU countries and some major economies such as China, India, Brazil, Russia, and the USA) but little detail for developing countries (Dietzenbacher et al., 2013). EORA database developed by Australian scholars has very good country coverage (186 countries) with a total of 15,909 sectors (but different countries have different sectoral resolution). It also published a harmonized MRIO table with 25 sector for each country and 186 countries from 1990 to 2011. However, the harmonized table only has one agriculture sector which is a limitation for land accounting analysis as agricultural sectors are the most land intensive sectors (Lenzen et al., 2013b). EXIOPOL (A new environmental accounting framework providing external costs and input–output tools for policy analysis) also focusses mainly on EU countries and it provides the tables only for the years 2000 and 2007. It covers 43 countries and the Rest of World (combining the remaining 150+

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countries), distinguishes more than 160 industry sectors and products (8 agricultural sectors), and covers 30 types of emissions and 80 resources by industry (Tukker et al., 2013). The availability of these large IO datasets has led to a scrutiny of the validity, comparability, uncertainty of the various products and the effects of differences in aggregation. For example, Owen et al. (2014) carried out a structural decomposition analysis to investigate the variations of regional consumption-based CO2 emissions based on three different MRIO databases: EORA, GTAP, and WIOD. They found that for a majority of regions, GTAP and WIOD tend to produce similar results. Whereas Steen-Olsen et al. (2014) found that the level of aggregation could influence results significantly depending on the purposes of the study.

Due to different sectoral, country and temporal resolution, different databases are suitable for different analyses. GTAP has more detailed agriculture sectors, thus is more suitable for analyses focusing on land and water. On the other hand, EORA, WIOD, and other databases have usually only one highly aggregated agriculture sector but very detailed industry and service sectors, thus are better suited for analyzing energy consumption and emissions from fossil fuels. In fact, MRIO analyses have been frequently applied to a range of human-induced environmental issues such as water consumption (Lenzen et al., 2013a; Yu et al., 2010), land displacement (Weinzettel et al., 2013; Yu et al., 2013), and carbon dioxide emissions (Davis and Caldeira, 2010; Kanemoto et al., 2012; Peters et al., 2011), SO2 and other more regional pollutants (Prell et al., 2014), materials (Bruckner et al., 2012; Giljum et al., 2014; Wiebe et al., 2012; Wiedmann et al., 2015), and biodiversity loss (Lenzen et al., 2012). The main advantage of MRIO analysis is that it is able to capture both direct and indirect environmental impacts along global trade networks (Miller and Blair, 2009; Wiedmann et al., 2010), another important advantage of MRIO analysis is that it provides the entire global supply chains as system boundary avoiding cut-off effects suffered by life-cycle analysis (LCA) and material flow analysis (Acquaye et al., 2011; Suh and Huppes, 2005; Wiedmann et al., 2011).

Despite this recent surge of MRIO-based applications for global environmental issues questions have been raised about the usefulness and accuracy of the MRIO approach to estimate land use associated with internationally traded products, for example, voiced by a recent paper by Kastner et al. (2014) using the example of China's trade in cropland products and embodied cropland, to make the case for a re-evaluation of the usefulness of using MRIO for estimating land footprints and implicitly for other environmental resources. Their criticism is based on an interesting observation that approaches based on physical trade matrices show that China is a major net importer of cropland products and embodied cropland, whereas MRIO based results suggest the opposite (see Fig. 1). The authors ". . . do not find convincing arguments that could explain these large differences and . . . question the plausibility of MRIO-derived results." (p. 140). Schaffartzik et al. (2015) reviewed approaches to accounting for upstream land of traded products across countries and found an overall similarity of results from both approaches but also diametrically opposed results for countries such as China, which according to the authors "make interpretation difficult" (p. 1). They concluded that "although results are often described using the same terminology . . . they must be interpreted as providing different types of information" (p. 8). In this study we want to investigate this claim further and explain the stated differences by comparing the estimates of cropland embodied in international trade for China in 2004 from studies using physical trade flow (PTF) data and MRIO analysis and provide a step-wise calculation to explain the gap between estimates from these different approaches and their interpretation.

Fig. 1 shows the differences of embodied cropland in China's international trade. Results are consistent within a chosen approach but differ markedly between approaches. For example, based on their physical trade flow (PTF) method, Meyfroidt et al. (2010), Qiang et al. (2013), and Kastner et al. (2014) found that China is a large net land importing country, with a net import of embodied cropland in China's international trade in the range of 16–20 million hectare (Mha), which was mainly due to the large net import of agricultural products. Whereas on the other hand, by applying MRIO, the studies by Weinzettel et al. (2013), Yu et al. (2013), and our own calculations in this paper show that China was a large net land exporting country, with net export of embodied land ranging between 8 Mha and 17 Mha. Weinzettel et al. (2013) and our own calculations using 2004 MRIO data and cropland data reached very similar results with about 1 Mha difference. However, Yu et al. (2013) was based on 2007 data which would explain the gap of the estimates to Weinzettel et al. (2013) and our own calculations but shows the same trend as the other MRIO studies in contrast to the physical trade flow studies. However, Kastner et al. (2014) could not find convincing factors to explain the gap between the PTF and the MRIO approaches and use it to question the validity of the MRIO approach. In this paper, we argue that this is based on a misunderstanding of interpreting results of the PTF and MRIO methods rather than a superiority of one over the other. Two recent review studies on this topic, Schaffartzik et al. (2015) and Bruckner et al. (2015), focused on accounting upstream land use in international traded goods with different accounting methods and provided some explanation on the factors that may lead to the observed differences in results between PTF and MRIO approaches. However, without support of proper modeling efforts using a consistent dataset, it is very difficult to understand the underling factors that may cause the differences in results. To better explain the differences, we compare the physical trade approach with three different methods based on monetary flow data to show in a stepwise fashion how China switches from being a net importer of embodied land based on an analysis using solely international trade flow data to a net exporter based on the MRIO approach. Such comparison is crucial as there are similar issues being raised for virtual water, and may be relevant to other environmental indicators. Note that the literature uses the terms virtual, embodied and embedded land or water interchangeably to refer to the direct and indirect use of resources along the entire supply chain.

There are fundamental differences between the PTF method and MRIO method. The PTF method focuses on the direct trade among regions or countries using international trade statistics. These physical trade flows are weighted by land requirements per unit of agricultural product (usually one ton) based on land use parameters (e.g., crop yield) for agricultural products in the respective countries, to derive embodied land in trade. The PTF method does not distinguish between products that are used as inputs during production processes (so called intermediate products) and final products and thus cannot comprehensively describe supply chain effects, which are crucial for allocating responsibility to final consumers, and identify driving forces. For example, plant-based fibers are imported to China as a primary agricultural product, but a substantial share (about one third) of the import is used for textile production, which is exported to other countries. Therefore, the entire part of the commodity chain beyond the first importing country is missing in the physical trade flow method. In addition, this approach mainly concentrates on land-intensive sectors such as food and other agricultural products, but lacks detail on industrial and service sectors, which use large quantities of these land-based sectors as inputs and thus indirectly consume large amounts of land. For example, cotton is usually used as input for clothing production, while international trade in finished clothing products are not included in the analysis of physical trade flows. In addition, MRIO distinguishes intermediate and final products, and also includes inter-sectoral flows in monetary value within