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Analysis

Does ecologically unequal exchange occur?

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ABSTRACT

The hypothesis of ecologically unequal exchange posits that low and middle income developing nations maintain an ecological deficit with wealthy developed nations, exporting natural resources and high impact commodities thereby allowing wealthy economies to avoid operating ecologically impactful industries at home. In this survey we assess the footprint of consumption of 187 countries using eight indicators of environmental pressure in order to determine whether or not this phenomenon occurs. We use input–output analysis with a new high resolution global Multi-Region Input–Output table to calculate each trading pair's balance of trade in biophysical terms of: GHG emissions, embodied water, and scarcity-weighted water content, air pollution, threatened species, Human Appropriated Net Primary Productivity, total material flow, and ecological footprint. We test three hypotheses that should be true if ecologically unequal exchange occurs. One: The inter-regional balance of trade in biophysical terms is disproportional to the balance of trade in financial terms. We find this is true, though not strongly so. Two: Exports from developing nations are more ecologically intensive than those from developed nations. We find this is true. Three: High-income nations disproportionately exert ecological impacts in lower income nations. We find this is false: high income nations are mostly exporters, not importers, of biophysical resources.

1. Introduction

Countries seek to maximize their welfare while minimizing the environmental cost of that welfare by decoupling economic growth from physical throughput. Undermining these efforts to improve resource efficiency are complex and opaque international supply chains through which the footprint of wealthy countries may be displaced into poorer countries where environmental protections may be less or sensitivity greater. In the context of CO_2-intensive production moving offshore, this phenomenon is called carbon leakage. In the broader context of natural resources being extracted from resource-rich but cash-poor countries to satisfy consumer demand in wealthy countries, it is called ecologically unequal exchange (Emmanuel, 1972; Hornborg et al., 2007; Martinez-Alier, 2007; Muradian and Giljum, 2007; Muradian et al., 2002; Røpke, 2001; Wallerstein, 1974).

In this study we simply ask whether or not ecologically unequal exchange does occur, not whether or not it ought to. In classical economic thought ecologically unequal exchange is a desirable, or natural, outcome since it is a result of specialization and trade. Countries abundant in natural resources should have more resource-intensive exports. However critics (e.g. Daly and Townsend, 1993; Norgaard, 1990; Rees and Wackernagel, 1999) reply that, due to a variety of market failures, natural resources and ecosystem services are often substantially under-valued and thus not allocated efficiently or equitably. It is predominantly pollution sinks, in air and water, and universally important resources, such as tropical rainforests, that are discussed as natural resources poorly allocated with their current prices (often zero).

We propose three testable hypotheses that should be true if ecologically unequal exchange is occurring:

1. The inter-regional trade balances in physical terms are not uniformly proportional to the financial balances of trade.
2. Exports from low-income nations are more ecologically intensive, that is, they contain more embodied environmental impact per dollar sold, than exports from high-income nations. Phrased in the inverse, low-income countries sell their natural resources more cheaply.
3. High-income nations exert a disproportionately large fraction of their ecological impacts in low income nations.

In this study we test these hypotheses empirically using a new high-resolution global multi-region input–output table. We have calculated the balance of trade between each of 187 counties in terms of eight indicators of environmental pressure: GHG emissions, air pollution, water and scarce water use, threatened species, Human Appropriated Net Primary Productivity, material use, and ecological footprint. These eight indicators together provide a broad measure of ecological pressure.[1]

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[1] The air pollution and species loss indicators are measures of impacts; the other indicators are measures of pressure. All the indicators strive to measure the actual, or risk of, impact. Below we generally employ the term impact even though this is not always strictly accurate as some indicators merely measure pressure not impact.

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2. Methods and Data

We tested the aforementioned three hypotheses by calculating the footprint[2] of eight biophysical indicators using Leontief's environmentally extended multi-region input–output (MRIO) analysis (Forssell and Polenske, 1998; Leontief, 1966; Leontief and Strout, 1963; Peters, 2008). Leontief's demand-pull method is most often used to determine the economy-wide (monetary or physical) repercussions of changes in final demand. It has also been used in various approaches to calculating balances of trade between the country suffering the impact (the producer) and the country whose consumers ultimately drive that consumption (Kanemoto et al., 2012; Serrano and Dietzenbacher, 2010). All impacts of production, intermediate processing, and transportation are attributed to final consumers,[3] in whichever country they reside. While much environmental impact occurs purely domestically, the acceleration of globalization means that more than ever consumers are driving environmental impact far beyond their own country's borders.

Leontief's approach is a standard technique for calculating each consumer's full footprint. Using the Eora MRIO (Lenzen et al., 2012a) table containing $n = 187$ countries each with between 26 and 501 sectors, for a total of $s = 15{,}909$ sectors, and evaluating $p = 8$ biophysical (or "satellite") indicator inputs,[4] the traditional per-country consumption footprint $\mathbf{F}$ $(p \times n)$ resulting from monetary expenditure y $(e \times n)$ of final consumers is $\mathbf{F} = \mathbf{Q}\hat{\mathbf{x}}^{-1}\left(\mathbf{I} - \mathbf{T}\hat{\mathbf{x}}^{-1}\right)^{-1}\mathbf{y}$, where $\mathbf{x}$ $(s \times 1)$ denotes per-sector gross output, the ^ operator denotes diagonalization, $\mathbf{T}$ denotes the $s \times s$ MRIO table and $\mathbf{I}$ an $s \times s$ identity matrix. $\mathbf{Q}$ $(p \times s)$ contains the per-sector direct impacts (t CO_2 emitted, Gl water used, etc.) and the term $\mathbf{Q}\hat{\mathbf{x}}^{-1}$ (hereafter $\mathbf{q}$) represents each sector's indicator intensity (direct impact per $1 of production). The eight indicators of ecological impact were attributed to production activities in each country. Details on the procedure differed by indicator, and are discussed below. The Leontief inverse was then applied in order to reattribute these impacts from country of production to the country in which the implicated products are finally consumed.

MRIO analysis of the world economy captures the entire international trade network; this means that when the resource requirements for final demand of a country D are appraised, MRIO analysis links D's final demand not only with its own domestic resource inputs, but also with the resource inputs in origins of D's imports. For example, if D imports products from C, and these were made using imports from B into C, and from A into B into C, then MRIO includes into D's footprint those resources used in A, B and C, ultimately serving to satisfy D's final demand.

The high sector detail of the Eora MRIO is important as it allows for better product differentiation thus mitigating error arising from sectoral aggregation. Consider aluminum production. If aluminum products are included in a broad 'nonferrous metals' sector the MRIO analysis will not be able to distinguish between embodied CO_2 in aluminum products, which are especially CO_2 intensive, and other nonferrous metal products, such as steel or copper which have a much lower CO_2 intensity (Allwood and Cullen, 2012). Distinguishing a separate 'aluminum' sector would provide a more accurate account of the embodied CO_2 in trade. While more disaggregation is conceptually always preferable, there are decreasing marginal returns to added detail. Su et al. (2010) found that diminishing returns sets in at ≈40 sectors, though Zhou et al. (2012) found that further disaggregation does improve accuracy. The Eora MRIO project explicitly aimed to preserve the full detail provided by national statistical bureaux and is the most detailed MRIO yet built.

The footprints of consumption calculated using the Eora MRIO database agree well with previously published results. As seen in Fig. 1 (reproduced from data in Lenzen et al., 2012a) there is good agreement between the final consumption footprint as calculated by Eora and other research groups. The figure compares Eora's results for the national footprint of final consumption for CO_2, ecological footprint, and embodied water with calculations of these same figures by Peters et al. (2011) (using GTAP 7; see Narayanan and Walmsley, 2008), Global Footprint Network (2010) and the Water Footprint Network (Mekonnen and Hoekstra, 2011). We see a small number of outliers in terms of ecological footprint, and a slight bias toward smaller water footprints in Eora, but overall substantial agreement.

2.1. Data Sources

For each indicator, the input data consist of a vector with the measure of the impacts associated with total production for each sector/product. Indicator datasets vary by level of detail; for example CO_2 emission inventories are accurate across all sectors of an economy while the water use data are highly accurate for various individual crops but more aggregated for all industrial and commercial uses. Using these data sources as satellite indicators for the Eora MRIO is further complicated by the fact that the Eora MRIO uses different sectoral classifications for each country (depending on the level of detail provided by each country's statistical bureau). These various conversions are accomplished with the use of concordance matrices. An $n \times m$ concordance matrix contains weights that can be used to map a source vector of length n to an output vector of length m. Each concordance matrix row specifies how source vector entries should be re-allocated amongst the various sectors of the destination vector, and each row sums to 1 in order to exhaustively re-allocate the source vector entries. Further explanation of concordance matrices is available (Geschke, 2012; Lenzen et al., 2012a) and specifics

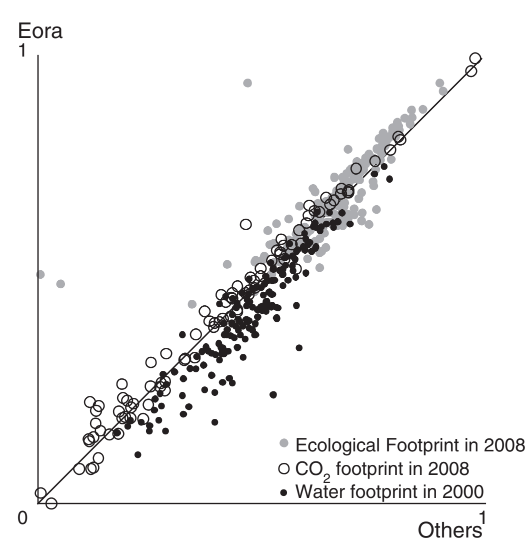

Fig. 1. Comparison of Eora per-country footprint of consumption (vertical axis) results with Ecological Footprint results from Global Footprint Network, water footprint results from the WaterStat database, and carbon footprint results based on GTAP ($y = 2008$) (horizontal axis). The vector of per-country footprints $\mathbf{f}_p$ for indicator p is first log scaled then linearly re-scaled such that $\max(\log_{10}\mathbf{f}_p) = 1$ and $\min(\log_{10}\mathbf{f}_p) = 0$ so that all three indicators can be plotted together.

[2] We use the lower case term "footprint" to refer generally to a consumption, not production, based account of environmental impact; the Ecological Footprint is one such account.

[3] In multi-region input–output analysis final consumption consists of purchases by households, government, NGOs, additions to inventories, and gross fixed capital expenditure. Note that in single-region variants of input–output analysis, exports form part of final demand, however in multi-region input–output analysis exports are endogenized into intermediate demand.

[4] Most of the eight indicators have multiple subcategories (e.g. CO_2 emissions are itemized by source type) so during calculation $p > 8$ to preserve this detail, but after the Leontief calculation $\mathbf{F}$ is aggregated back to $p = 8$ for subsequent analysis.