A Global Multi-Region Inputâ€"Output Model Incorporating Container Shipping Networks: Model Development and Empirical Analysis

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The global supply chain (GSC) structure has significantly developed over the past few decades driven by the expansion of international trade. 23% of global CO2 emissions are embodied in traded goods through GSCs, making the reduction of CO2 emissions from GSCs a matter of significant concern for achieving carbon neutrality worldwide. Environmentally Extended Multi-Regional Input-Output (EE-MRIO) models are one of the most powerful tools for tracing GSCs and allocate emissions from production to consumption across countries.

In Input-Output Analysis, Multi-Regional Input-Output (MRIO) tables describe inter- and intra-industry dependencies within and between countries by modeling GSC as a multidimensional space defined by country, commodity, and industry. However, MRIO tables do not provide insights into the domestic and international transportation systems used for these trade flows, as the path through physical space is not explicitly defined.

On the other hand, it is important to note that the development of the GSCs has led to the geographic separation of production areas and consumption areas, which makes the GSC highly dependent on international shipping. To more accurately evaluate the environmental impact of GSCs, it is essential to develop analytical methods that incorporate physical dimensions. Accordingly, this study aims to construct a global multi-regional input-output model incorporating container shipping networks and develop a new framework to evaluate the environmental impact of the entire GSCs, including not only production and consumption but also international shipping.

In this study, we first estimated value of direct and indirect input (dollar) induced by world final demand by multiplying Leontief inverse matrix with final demand vector using Global Environmentally-Extended Multi-Region Input-Output Database (GLORIA). Next, we calculated the ratio (%) of container transport by industry and country based on trade statistics data and estimated Japanâ€™s import value (dollar) by container transport. By multiplying the container transport ratio matrix with value of direct and indirect input, we estimated the value of direct and indirect input that is transported by container ships based on MRIO approach. Additionally, we utilized big data on international container shipping to calculate offshore CO2 emission intensity (t-CO2/dollar) for international container shipping. Finally, we multiplied offshore CO2 emission intensity (t-CO2/dollar) for international container shipping with the value of direct and indirect input transported by container ships to estimate total offshore CO2 emission (t-CO2) based on an MRIO approach.

Results show that the estimated CO2 emissions vary across the three models. The bottom-up estimation of CO2 emissions from container ships towards Japan based on AIS data, which records all ship movements, was 8.2 Mt-CO2. In contrast, the estimation for the â€œWater Transportâ€• sector based on the EE-MRIO model was 3.8 Mt-CO2, capturing only 46% of the shipping emissions associated with Japan's imports. On the other hand, the estimation based on the model developed in this study was 7.9 Mt-CO2. Although this model employs a top-down estimation approach based on trade structure, it yields values consistent with those derived from operational databases.

The gap between the EE-MRIO estimates and operational databases suggests the necessity of explicitly incorporating container shipping networks into EE-MRIO models. Furthermore, when discussing the environmental impact assessment and decarbonization policies of GSCs based on

EE-MRIO, it is essential to explicitly incorporate international transportation as a structural element rather than treating it as an exogenous factor.