Identifying the Driving Factors of CO2 Emissions in a Global Multi-Regional Unit Structure

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Globalization has expanded global supply chains (GSCs), increasing CO2 emissions embodied in them. Because production and associated COâ‚‚ emissions are induced across borders through complex GSC networks, identifying emissions embodied in GSCs is essential for effective decarbonization policy.

Japan relies heavily on imported resources, and its industries are strongly supported by GSCs. For example, when China imposed export restrictions on rare earth elements last year, supply chain disruptions led to partial shutdowns of automobile production in Japan. In the Japanese automobile industry, which increasingly procures diverse components from domestic and foreign sources, the growing influence of GSCs highlights the importance of understanding GSC structures to ensure stable future production.

Given supply chain risks and the goal of carbon neutrality, understanding the structure of GSCs and reducing CO2 emissions within them is critically important. Therefore, two key research questions arise: What is the structure of expanding GSCs, and where and how much COâ‚‚ is emitted? Furthermore, what factors drive these emissions? To address these questions, this study introduces a new analytical framework integrating global multi-regional unit structure analysis and structural decomposition analysis (SDA) to quantify emission structures and driving factors. This novel approach enables the identification of emission hotspots within GSCs at a detailed transaction level and the factors contributing to emissions embodied in each transaction.

The novelty of this study is twofold. First, this study extends SDA by adapting it to a global multi-regional unit structure model, enabling the decomposition of the driving factors behind emission changes at a detailed inter-industry transaction level, triggered by the final demand of a specific sector. Notably, this framework explicitly distinguishes trade and technological effects within the global unit structure of a final product and decomposes emission changes embodied in the productâ€™s GSCs into three main driving factors: emission intensity effect, trade structure effect, and production technology effect.

Second, this study provides the first transaction-level quantification of long-term structural changes in Japanâ€™s automobile GSCs over the past two decades. Using linked multi-regional input-output tables based on ADB-MRIO from 2000 to 2021 in constant prices, covering 63 countries and 35 sectors, CO2 emissions induced by final demand in automobile industries through GSCs are estimated. By comparing global multi-regional unit structures of Japanâ€™s automobile industry between 2000 and 2021, this study identifies structural changes in automobile GSCs and the corresponding changes in embodied emissions.

The results show that the share of industrial transactions with China in Japanâ€™s automobile GSCs increased from 5.7% in 2000 to 11.6% in 2021, doubling over the period. This indicates an increasing dependence on supply chains linked to China for raw materials and components and a corresponding rise in induced emissions in China. Meanwhile, total emissions embodied in Japanâ€™s automobile GSCs decreased by 35% over the past 20 years. The largest reduction occurred in transactions from â€œbasic metals and fabricated metals in Japanâ€• to â€œtransport equipment in Japan,â€• with declines observed not only domestically but also in trade with Russia

and Australia. Improvements in emission intensity contributed most to this reduction (67%), followed by advances in production technology. However, at the current pace, achieving the 2050 carbon neutrality target remains difficult, indicating the need for further improvements in emission intensity and production technology.

In contrast, changes in trade patterns increased emissions, offsetting about 20% of the total emission reductions. Large emission increases were observed in â€œelectricity supplyâ€• transactions in Japan and China, as well as the â€œbasic metals and fabricated metalsâ€• sector in China and Indonesia. One of the most important findings is that changes in trade structures weakened the overall emission mitigation effect by offsetting reductions achieved through improvements in emission intensity and technology.

These findings highlight the importance of considering changes in trade structures, in addition to technological and efficiency improvements, when designing supply-chain-based decarbonization strategies. To reduce COâ„‚ emissions embodied in Japanâ€™s increasingly global supply chainâ€“dependent industrial structure, policymakers are encouraged to carefully examine trade patterns in key transactions identified in this study and to incorporate environmental considerations into trade arrangements in this crucial industryâ€”the automotive sector of the Japanese economy.