Integrated Supply Chain Hotspot Analysis Using Forward and Backward Input-Output Unit Structures

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With the goal of achieving carbon neutrality by 2050, industries that accounted for approximately 25% of Japanâ€™s total CO2 emissions in 2019 are required to reduce their energy-related emissions. At the same time, Japan is experiencing sudden inflation due to rising global prices of imported energy resources and raw materials. Therefore, it is crucial for policymakers to mitigate both the cost burden of energy and material imports and the energy-related CO2 emissions from industrial activities.

It is important to note that CO2 emissions and importation costs are inherently linked when considering domestic fossil fuel consumption. Japan relies on imported fossil fuels for over 95% of its primary energy needs. Reducing fossil fuel usage provides industries with dual benefits: alleviating import cost burdens and decreasing CO2 emissions.

Developing effective policies that emphasize the connection between importation costs and CO2 emissions is critically important. This leads to a key research question: Which industries are most affected by the combined impacts of these costs and emissions? To address this question, this study introduces a new analytical framework for quantitatively evaluating the comprehensive impacts of importation costs and CO2 emissions on Japanese industries. This framework integrates two distinct input-output models: the input-output quantity model and the input-output price model.

The novelty of this study is twofold. First, it introduces an innovative input-output analysis framework by utilizing two types of forward and backward unit structure models based on the input-output quantity and price models, respectively (e.g., Kagawa et al., Economic Systems Research, 2013; Tsukioka and Kagawa, Economic Systems Research, 2025). The integrated unit structure analysis framework enables us to assess both the forward price impacts of changes in energy import costs and the backward CO2 emission impacts of changes in final demand for goods and services.

Second, this study applies supply chain cluster analysis to the integrated unit structures, triggered by changes in both a specific imported energy price and the final demand for a specific commodity. This approach identifies critical supply chain clustersâ€”industrial hotspotsâ€—that face the highest energy cost pressures and energy-related CO2 emissions due to external shocks.

This study utilizes the 2015 input-output tables (IOTs) with the highest sectoral resolution available for Japan. Additionally, it incorporates a time-series dataset on imported energy prices for crude oil, coal, and natural gas to calculate the average rate of price increases for each imported energy resource. Direct sectoral CO2 emission intensity is also assessed to estimate the CO2 emissions induced by final demand in domestic industries.

Using the 2015 input-output tables, I identify the iron and steel supply chain as a critical hotspot, significantly affected by coal costs and CO2 emissions from fossil fuel use. Cluster analysis reveals that the crude steel-related clusterâ€—which includes â€˜crude steel, with converters,â€™ â€˜coal products,â€™ and â€˜pig ironâ€™â€—is a major hotspot, heavily impacted by high coal costs. This cluster exhibits significant CO2 emissions, particularly driven by the motor vehicle industry. Additionally, I find that chemical-related clusters, including â€˜aliphatic intermediates,â€™ â€˜cyclic intermediates,â€™ and â€˜methane,â€™ are notably affected by crude oil cost pressures and CO2 emissions.

Based on the supply chain cluster results identified in this study, policymakers should prioritize financial support for industries in critical hotspots facing the highest pressures from importation costs and CO_2 emissions. For example, I recommend that the Japanese government increase investments in greener technologies for key hotspots such as the iron and steel industries to reduce reliance on fossil fuels.