Literature Review on the Application of Input-Output Analysis to Trade and the Environment

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Production fragmentation has changed the distribution pattern of value added and thus emissions among countries. As a consequence, the gross trade statistics and territory-based emissions cannot reveal the real picture and generate misleading conclusions. In this aspect, input-output analysis, which describes the interdependence among industries and countries, becomes the suitable tool to reflect the true story and answer questions like "where is the value-added come from" and "who emits for whom". Under this background, this paper reviews the relevant researches that use input-output analysis to study trade and its impact on the environment, from which we can also understand the development of input-output analysis over time.

Keywords: input-output analysis, trade, the environment, embodied emissions

1. Introduction

Input-output model, developed by Nobel Prize laureate Wassily W. Leontief in 1950s, describes the input-output interdependence among sectors (Miller and Blair, 2009). After almost seven decades of development, the input-output model has been an important tool to analyze global value chain and embodied factors in trade, decompose the source of value-added in final products, and account for the factor inputs (such as labor, capital, energy, land, water etc.) in different production stage of final products. In particular, with the development and openness of world input-output tables, global value chain and related issues (such as embodied emission accounting) have been widely analyzed. Next section reviews the related literature that applies input-output analysis to two aspects: trade and the environment.

2. Literature Review

2.1. The Application of Input-Output Analysis in the Area of Trade

With the decreasing transport and coordination cost, the production chain is

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becoming more and more fragmented. As a consequence, countries specialize in one or more tasks of the production chain and the values of final products are dispersed among countries (Baldwin, 2006). Under this background, the concept of "global value chain" is introduced, which describes the values generated along the production chain from raw materials to the final product that ends in consumers' hands.

Take the smartphone as an example. Suppose China exports a $300 smartphone to United States. China may only produce $10 of the total value of the phone. The rest of it is imported from other countries: graphic design from California, metals mined in Bolivia, Silicon chip from the factories in Singapore etc. (Xing and Detert, 2010). However, when the traditional trade statistical method is applied, the import of this phone increases the US trade deficit with China by $300. Thus, the traditional trade data cannot reflect the true story. To fully understand the trade, we need to trace the value added by countries in producing this phone.

Due to the lack of aggregate data, the first research works are limited to firm's or product's micro-level. For instance, Dedrick *et al*. (2010) and Xing and Detert (2010) investigate the value chain of Apple products.

The firm-or production-level researches only consider the value added structure of first tier suppliers and are limited to macroeconomic issues. Meanwhile, researchers find that the statistics of exports are misleading, so they switch their attention to a macro level to explore the value composition of exports. Large proportion of these researches focuses on measuring international fragmentation in value chains. The calculation of trade in value added requires data not only on production process, but also on the direction of trade in every stage of the production of goods. Hence, the input-output tables, which include imported input, output and exports, tend to be an appropriate analytic instrument. Lots of projects are set up to construct multinational input-output database in order to provide a consistent set of information to facilitate the comparison among sectors, countries and over time.

Hummels *et al.* (2001) introduced the vertical specialization and developed two indicators to measure it. The primary measure (VS) measures the value of the imported inputs embodied in goods and services that are exported. VS equals to the total value of direct and indirect intermediate imported goods divide the gross export. The second measure (VS1) measures the value of exports that are embedded in a second country's export goods. Using the input-output matrices of 10 OECD countries and 3 non-OECD countries, they found the vertical specialization grew almost 30% between 1970 and 1990. Meanwhile, the growth in vertical specialization accounted for 30% of the growth in these countries' exports.

A shortcoming of the primary measure of vertical specialization is that it does not capture a country's participation in global value chain if the country specializes in the first stage of the production process, i.e. if a country's exports are used in the subsequent stages of the production process of an export good in another country.

This kind of participation can be measured by “vertical specialization 1” in literatures (Hummels *et al.*, 2001). Put this into consideration, Daudin *et al*. (2011) calculated the imported value embodied in exports (VS) and exports used by other imported countries to produce input for exports (VS1), using the database of the Global Trade Analysis Project(GTAP). They used the ratio of VS1 over VS to distinguish two types of participation in the international fragmentation of the production process. The VS1 to VS ratio for primary producers and producers of industrial input for processing countries took part in global value chains through the production of inputs for further exports, are bigger than one. Other countries as the final exporters have VS1 to VS ratio smaller than one. Their paper confirmed that Asia, America and Africa relied more heavily on extra-regional final markets than standard trade statistics suggest. European Union is less dependent on vertical specialization trade.

Koopman *et al*. (2010) further constructed a framework that can integrate both indicators. This framework divided exports into two value-added parts, domestic and foreign. Moreover, the domestic value-added component could be decomposed into three parts: absorbed value added exports, indirect value added exports and reflected domestic value added. They applied the decomposition to compute revealed comparative advantages and construct an index to describe whether a country-sector is likely in the upstream or downstream of global value chain.

As been pointed out in Koopman *et al*. (2010), this composition equation traced only the direct effect and the first round of the indirect effect, which meant that this method ignored a probability that the value added embodied in an intermediate could travel through many sectors before it is exported. Johnson and Noguera (2012) constructed another indicator to measure the “domestic content of exports”—VAX ratio. Using the GTAP database, VAX ratio is calculated for 87 countries and regions as a measure of the intensity of production sharing. Moreover, they investigated the direction of the bilateral trade—whether the exports were absorbed in the destination country, redirected to a third country, or reflected to the origin export country. Results showed that China, as a production sharing hub, has a relatively lower absorption rate of imported goods and a high proportion of imported goods used for exports.

Previous studies concentrated on investigating the value added in direct trade-specific-relationship among countries, Meng *et al*. (2012) started to consider the intercountry production network among countries. He distinguished two concepts—value added in trade and trade in value added. The later one is expressed through two types of VAiT—value added embodied in its exports when the single I-O model is used and the value added induced by the trade in intermediate goods from exporters to importers. They applied the concept of trade in value added to study the evolution of regional economic integration and global value chains, answering questions “who produces intermediates for whom”. Furthermore, they explored to evaluate comparative advantages on the basis of trade in value added.

Increasing fragmentation is changing the international competition and factor income distribution. Another stand of literature studies the socio-economic effect of production fragmentation from the global value chain perspective. Timmer *et al*. (2012) proposed the so-called “global value chain income”, based on the value added each county contributed to the final manufacturing goods, to reveal each country’s competitiveness and also the revealed comparative advantage. In addition, Timmer *et al*. (2013) used the decomposition technique to “slice up the value chain” and analyzed the factor income distribution structure. They found that the value added share of high-skilled labor and capital was increasing while the share of low-skilled labor was decreasing. Furthermore, under the same framework, Los *et al*.(2014) showed that the share of value added outside the country is dominated by the regional production system, while the share of value added outside the region that country belongs to is growing faster than that inside the region.

Recent researches suggest that the level of vertical specialization would be underestimated for countries have a high share of processing trade, since the imported share embodied in processing trade in higher than that embodied in traditional exports. Koopman *et al*. (2008) proposed a mathematical programming procedure to estimate the coefficients of processing sectors by combining trade statistics with original input-output tables. Dean *et al*. (2008) compared the vertical specialization estimated by both the HIY method with the one obtained by applying the method proposed by Koopman *et al*. (2008). Results showed that the later method provided higher VS share. Nevertheless, these two methods identified a similar list of sectors which have high level of vertical specialization. Chen *et al.* (2012) also distinguished the effect of non-processing industries and processing industries. Results showed that non-processing exports have higher total domestic value-added (DVA) and domestic employment effects in all sectors than processing exports. They also reported that traditional manufacturing exports, such as textile and garment products, generated higher total DVA and employment than “high-technology” manufacturing exports such as electronic equipment and machinery or telecommunication equipment, computer and other electronic products.

Lots of literatures are involved in investigating the underlying reasons of increasing trend of production fragmentation. Venables (1999) showed that the high production fragmentation was possible, only when transport costs were lowered. Yi (2003) constructed a theoretical model to investigate the effect of global tariffs reductions on trade flow. Results showed that the vertical specialization can serve as a propagation mechanism magnifying the impact tariff reduction, which led to large increase in trade. Moreover, tariff reduction led to more goods becoming vertically specialized.

Freund (2009) analyzeed the impact of historical global downturns on trade flows. There were four such events in recent history: 1975, 1982, 1991 and 2001. He found that the elasticity of global trade volumes to real world GDP had increased from under

2 in the 1960s to over 3.5 in 2000s. He argued that the increase in income elasticity of trade resulted from the fragmentation of production. If there is more incentive to outsource part of the production chain when demand was high, then the elasticity of trade to GDP would rise. This statistic measure effect partly explained why the decline in trade was higher than that in GDP and the discrepancy was magnified by global production chain, as the production process cross several national borders.

Escaith and Gonguet (2009) investigated the role of global production chain as transmission channels of a financial shock, in the form of credit constraint. They proposed a supply-chain indicator and calculated the secondary demand-driven impact on five economies with different properties: China, Japan, Malaysia, Thailand and the United States. The results showed that when countries are linked through global production chain, firms are interdependent on each other. Then an effect of financial shock would propagate to other countries through the production chain. The relative shock on the domestic economy depended on its degree of openness and also the relative size of originating sector in relation to the rest of the economy. Yi (2009) also argued that vertical specialization acted as a transmission mechanism of domestic shocks and that contributeed to the synchronized decline in trade between 2008 and 2009.

2.2. The Application of Input-Output Analysis in the Area of the Environment

2.2.1. Related Researches on Embodied Emissions from the Perspective of Global Value Chains

Economic globalization has changed the pattern of environmental impact of international trade; therefore, it is of important significance to analyze the emission effect of trade. In the earlier researches, Wyckoff and Roop (1994) estimated the embodied emissions in the imports of six countries (the USA, Germany, the UK, France, Japan and Canada) in the Organization for Economic Cooperation and Development (OECD). They found that these developed countries were significant importer of high emission intensive products, and the embodied emissions in imports equaled to 13% of their domestic emission. Similarly, Machado *et al.* (2001) used single input-output table to analyze the embodied emissions in trade for Brazil. Results showed that for Brazil, emissions embodied in exports were larger than those embodied in imports. In contrast, for India (Dietzenbacher and Mukhopadhyay, 2007), the opposite results from theoretical prediction were found, that is, embodied emissions exports were smaller than those in imports. This phenomenon was called "Green Leontief Paradox", which has caused widely research into the related issue in the academia.

Due to the data limitation, earlier researches on estimating embodied emissions in trade mainly assumed the emission intensities of imports were similar as those of domestic products. Obviously, this assumption cannot accurately describe the embodied emissions in imports, while the construction and application of multi-regional input-output table can successfully overcome this drawback. The increasing availability of multi-regional input-output table enriches the researches that study the related issues. For instance, Ackerman *et al*. (2007) used the US-Japan two-country input-output table and counterfactual analysis to show that the US was a net emission importer from Japan, that is, part of the emissions in the US were shifted to Japan. Peters and Hertwich (2008) applied the multi-country input-output model and analyzed the embodied emissions in trade for 87 countries. Results showed that the member countries in Kyoto Protocol were net emission importers. Therefore, embodied emissions in international trade have a significant influence on the effectiveness of global emission alleviation policies. They proposed that to alleviate the impact of trade on the effectiveness of global emission reduction policies, several countries should form a union to take the emissions responsibility mutually. In recent, Wiedmann (2009), Liddle (2018) and Meng *et al*. (2018) made a detailed literature review on the studies that used multi-regional input-output model to analyze the consumption-based emissions. Recent researches all show that developed economies have shifted the emission-intensive production to economies with lower energy (or resource) productivity. As a consequence, the total use of energy (or resource) has increased, which has induced more emissions (Lan *et al.*, 2016; Plank *et al.*, 2018; Xiao *et al*., 2019). Duan and Yan (2019) further explored the temporal changes and driving forces of China's environmental losses relative to its economic gains from international trade with each of its 45 trading partners from 1995 to 2015. Results showed that China suffered larger environmental losses per value-added through exports than most of its trading partners, but it declined quickly. Technique effect was the main contributor to this decline. Meanwhile, the outsourcing of dirty intermediate production stages from developed economies has led emerging economies suffering greater environmental losses per value added through trade.

The above mentioned studies have ignore one significant characteristics of China's import and export trade, that is, the processing exports account for relatively high percentage in total exports. The characteristics of processing exports is that part or all of the intermediate inputs are obtained from imports (Lau *et al*., 2007; Dietzenbacher *et al*., 2012; Su *et al.*, 2013; Weitzel and Ma, 2014; Duan *et al.*, 2014; Pei *et al.*, 2012). Therefore, the intermediate input structures for processing exports and ordinary products (non-processing products) are totally different: the intermediate inputs of processing export products are mainly from imports, while those for ordinary products are supplied by domestic production. The traditional input-output model assumes the same intermediate input structure for processing export products and ordinary products and does not distinguish different production structure for different production types, which, therefore, leads to biased estimation of embodied emissions.

In this area, Chen *et al.* (2012), Koopman *et al.* (2012), Pei *et al*. (2012) and Su *et al*. (2013) employed different method to distinguish different trade mode in China's single country input-output table and found that compared to other production, one unit of processing exports induced less domestic production activities and therefore less domestic value-added. Pei *et al*. (2012) further proved that input-output model without distinguishing trade heterogeneity would overestimate the economic contribution of exports. In particular, Dietzenbacher *et al*. (2012) found that the induced domestic emissions by China's exports would be overestimated by 60%, if the same intermediate input structure was applied for processing exports and ordinary production. Jiang *et al.* (2016) reexamined the embodied emission movement by splitting the Chinese production in multi-country input-output table into three types (domestic final products, processing exports and non-processing exports). Compared with the new multi-country input-output model, traditional model overestimated the net embodied emissions exports from China to other economies by 15%. By applying the multi-regional input-output model that distinguishes processing production from ordinary production, Yan *et al.* (2019) found that the environmental losses from exports were overestimated by 14%–25% in 2002 and 7%–20% in 2012 for different regions, when the traditional multi-regional input-output model is used. Regions and industries with the highest processing export shares are found to have the largest biases.

2.2.2. Related Researches on Embodied Emissions/Energy in Domestic Value Chains

Promoted by international negotiation, the environmental impact of international trade, such as "emission transfer" and "emission leakage", has attracted many attentions from both domestic and foreign scholars. At the same time, the emission transfer induced by industrial relocation among regions in China started to be a hot research topic since the 11th Five-Year Plan (considering the realistic need of allocating the emission reduction responsibility into different regions). For instance, Yao *et al*. (2010), Feng *et al*. (2013), Xiao *et al*. (2014) and Zhang *et al*. (2016) applied the input-output technique to explore the embodied emissions transfer among eight regions in China. Results showed that similar as the international trade, the transfer pattern of embodied emissions that developed regions outsourced emissions to under developed regions also existed among eight regions in China. Take the year of 2007 as an example, 80% of the emissions embodied in the final demand in developed regions were emitted in under developed regions. The related researches (Meng *et al*., 2012; Zhang and Tang, 2015; Meng *et al*., 2017; Liu and Wang, 2017; Wu *et al*., 2017; Duan *et al*., 2018) further showed that the emissions generated in underdeveloped inland regions were not only induced by its exports, but also driven by participating in the production chain of coastal regions.

Furthermore, scholars compared the energy intensity changes across regions and over time and analyzed the driving forces of such changes. The related literature can be roughly divided into three categories. The first category explored the energy saving potential of eliminating energy intensity difference among regions (Rao *et al*., 2012; Liu *et al*., 2016; Shao, 2017). The second category studied the influence factors of energy intensity gap among regions. Among this category of literature, one strand of literature used Stochastic Frontier Analysis (SFA) or Data Envelop Analysis (DEA) to analyze the influence of factor inputs (such as labor and capital) on energy intensity gap among regions (Hu and Wang, 2006; Li and Lin, 2015; Wei *et al*., 2009). The other strand of literature used the Index decomposition Analysis (IDA) (Song and Zheng, 2012; Lin and Du, 2014; Jiang *et al*., 2017) or Structural Decomposition Analysis (SDA) (Liao *et al*., 2013; Zhang and Lahr, 2014) to decompose the regional energy intensity gap into several independent factors. For instance, Jiang *et al*. (2017) decomposed the regional energy intensity gap into energy efficiency, industrial structure and consumption structure. The third category analyzed the driving factors of the temporal changes of regional energy intensity. In a similar way, most of the related studies used IDA (Zhang and Nie, 2008; Choi and Ang, 2012) and SDA (Zhang, 2003; Ang *et al*., 2003; Xia *et al*., 2009; Cai *et al*., 2011; Zeng *et al*., 2014).

3. Conclusions

Above all, production fragmentation has changed the distribution pattern of value-added and thus emissions among countries. As a result, the gross statistics and production-based emissions can no longer reveal the real picture and thus generate misleading conclusions. In this aspect, input-output analysis, which describes the interdependence among industries and countries, is the suitable tool to reflect the real picture and answer questions like “where is the value-added come from” and “who emits for whom”. In recent studies, input-output analysis is also combined with other techniques, such as DEA (Fujii and Managi, 2015) and linear/non-linear programming (Strømman *et al.*, 2008), to analyze the emission reduction potentials through industrial structure adjustment or other policies. Of course, input-output analysis has its own limitations, such as the assumptions that each industry only produces only one product, the input-output structure is fixed and linear, prices are not modeled into the framework, etc. Depending on the specific research questions, input-output analysis can be combined with other techniques, like econometric analysis or industrial assessment model to overcome the above mentioned drawbacks.

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