THE ANALYSIS OF CARBON DIOXIDE EMISSIONS FROM TAIWAN'S EXPORT INDUSTRY

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Abstract. By reviewing Taiwan's economic development after the Second World War, economic activities at various stages are driven by international trade exports, which has led to Taiwan's economic growth and rising per capita income. Therefore, the situation of Taiwan's export industry is of great significance to its development. In this study, the Environmental Input-Output (EIO) model, the World Input-Output Database (WIOD), and Socio-Economic Accounts are used to investigate the CO_2 emissions of Taiwan's export industry sectors and its relationship with other countries. It is analysed how particular export sectors cause carbon dioxide emissions in domestic production supply chains (by tracking downstream to upstream), and how carbon emissions in specific sectors affect export output. The empirical results show that the growth rate of CO_2 emissions in Taiwan's export industry is roughly the same as its GDP growth rate and far lower than Japan and the United States. From the perspective of industry categories, water transport, chemical products and electronic optical products are Taiwan's export sectors with high CO_2 emissions and rapid growth.
Keywords: *environmental input-output (EIO) model, Taiwan export sector, GDP, emission growth rate, supply chain*

Introduction

With island-type economy and poor natural resources, Taiwan takes the export-oriented trade as the most important industry under the government's pursuit of industrial development. At the end of the 20th century, with the development of the Internet and the commercial application of new technologies, the cost of transnational operations of enterprises declined, and information systems made transnational supply chains and management more convenient. As China and Taiwan joined the WTO successively in 2001 and 2002, global trade has become increasingly more achievable under the globalization trend and the elimination of WTO trade barriers. In the past, most of the global trade was concentrated in the North American and EU markets, while in recent years, with the rise of Chinese economy and the expansion of the ASEAN (Association of Southeast Asian Nations) from the first four countries to ten countries, as well as the signing of the Free Trade Agreement (FTA), the focus of trade around the world has been shifted to the Asian region.

In recent years, as China's economy has shown a fast-growing trend for a long term, the open-door policy will inevitably deepen its dependence on international

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market (Lu, 2018). Thus, many Taiwanese businessmen have gone to the mainland to invest in the local development (Lin and Yang, 2017; Rigger, 2015), and the industrial division of labor between Taiwan and mainland has shown a weakening vertical division and a more common horizontal division. The proportion of Taiwan's export products in *Table 1* shows that the first major export products in Taiwan are electronic components, and the proportion has increased year by year, reaching 33% in 2016. The second is audio-visual products, accounting for about 10% in the past ten years. The third is metal products, the proportion of which continues to decline, and the proportions of mineral products, petroleum refining products and textiles have also declined due to the change in industrial structure.

Table 1. *Structure of Taiwan's export products (unit: %)*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Electronic components	22.2	21.4	24.3	24.9	24.1	24.5	25.9	28.2	30.1	33.1
Audio-visual products	11.6	10.0	10.5	11.2	11.7	10.3	10.0	9.7	10.7	10.8
Metal products	11.2	11.0	9.4	9.4	9.7	9.2	8.9	9.1	8.9	8.8
Mechanical products	7.1	7.0	6.1	6.7	7.2	7.3	6.9	7.2	7.5	7.5
Plastic rubber products	7.6	7.7	8.1	8.0	8.1	7.9	8.0	7.6	7.4	7.1
Chemical products	6.0	6.8	6.9	7.0	7.3	6.9	7.0	6.9	6.4	6.1
Optical equipment	7.1	7.6	6.9	7.6	6.7	6.7	6.3	5.6	4.5	4.1
Mineral products	5.7	7.4	5.7	5.3	5.8	7.3	7.8	6.7	4.2	3.9
Petroleum refining products	5.4	7.0	5.3	5.0	5.5	6.9	7.3	6.2	3.6	3.4
Motor products	6.9	6.2	5.7	5.2	4.0	4.2	4.4	4.1	4.1	3.4
Conveyance	3.2	3.5	3.8	3.4	3.3	3.6	3.5	4.1	4.1	3.9
Textiles	4.7	4.2	4.5	4.1	4.1	3.9	3.8	3.8	3.8	3.5

Data source: National Statistics, R.O.C. (Taiwan)

Intermediate goods of various semi-finished products and components account for a high proportion of Taiwan's exports, which are combined with the production factors of exporting countries and sold around the world. In other words, the various interdependent items in international trade form an industrial chain. Nowadays, countries all over the world are developing industrial structures, adjusting economic physique, and claiming to comprehensively improve the self-made rate (Meng et al., 2017; Ritchie et al., 2018), then if Taiwan cannot upgrade its industrial structure and develop an "independent economy" model, it will inevitably be affected by a strong economic impact. The development trend of global trade is particularly significant in the vertical division of labor. The international vertical division of labor is the multi-nationalization of production process, so that the final production of goods is completed through different manufacturing processes in many countries. In Taiwan, the production of components relies on the import of raw materials, which will generate carbon dioxide (CO_2) in the production process. Therefore, this paper intends to understand how much carbon dioxide emissions are generated due to exports, and to explore the correlation analysis of how the downstream export industry can drive carbon dioxide emissions from domestic upstream industry.

This paper explores the comparison of CO_2 emissions between industries in Taiwan and its major exporting countries, and uses the Environmental Input-Output

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(EIO) model to provide an in-depth understanding of the sources and structures of CO_2 emissions from the countries. Based on the above research motivation, the main purpose of this paper is to understand the industrial input-output structure and industrial linkage profile of each country according to the input-output tables from the World Input-Output Database (WIOD). The Socio-Economic Accounts from 1995 to 2011, and the old and new versions of WIOD from 1995 to 2011 and from 2000 to 2014 are used to analyze and compare the change in the trends of CO_2 emissions from industrial exports in countries under the global value chain.

Literature review

There are four types of assessment methods for the impact of international trade on the environment in the literature. The first type is Structural Path Analysis (SPA), which refers to the use of input-output analysis to track complex production processes under given final demands. The traditional SPA method only explores one single region, and if the upstream and downstream industrial chains of a product belong to different countries, it will be impossible to discuss the single affiliation problem, such as Lenzen (2003), Peter and Hertwich (2006); the second type is Hybrid Input-Output Analysis, which refers to the use of input-output tables composed of price units and material units to distinguish energy from non-energy, such as Kagawa and Inamura (2001), Dietzenbacher and Stage (2006).

The third type is Multi-regional Input-Output Analysis (MRIO), which refers to that the single-region input-output table is estimated and broken down into a multi-region input-output table under the traditional SPA model framework, so as to calculate the industrial correlation effects on output and pollution emissions in various regions through the final demand and correlation matrix of each region. Since the unit output value, output and even proportion are required for the use of mixed unit model, the difficulty of data collection is a major shortcoming, such as Lenzen et al. (2004), Peter and Hertwich (2006). The fourth type is the EIO model, that is, the use of multi-regional input-output method to extend the regional model derived from the environmental coefficient, so as to gain a deeper understanding of the sources and structures of carbon dioxide emissions from countries' exports and explore climate policies regarding carbon leakage formulated by various countries.

In the past literature, Peter and Hertwich (2006) used the SPA method and the MRIO method to explore the environmental impact brought by the Norwegian international trade. The results show that in terms of household consumption, 80% of the direct emissions of personal fuels environmental impact are the transportation consumption of the households. In the government consumption sector, government expenditures are mainly in the medical treatment, education, and public administration departments, whose public sector has a greater impact on the purchase of transportation vehicles. If compared with households and export sectors, the government's pollution discharge density is relatively low.

Jin et al. (2017) analyzes a few scenarios of Korean CCS projects with a CO_2 pipeline transportation network optimization model for minimizing the total facility cost and pipeline cost. The results for each scenario demonstrate that the effective design and implementation of CO_2 pipeline network enables the lowering of CO_2 units cost. Liu et al. (2016) analyzed the impact of corporate heterogeneity by using

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the EIO model, and found that ignoring corporate heterogeneity may lead to overestimation of carbon dioxide emissions from China's export.

Materials and methods

Data description

The database used in this paper comes from the World Input-Output Database (WIOD). Dietzenbacher et al. (2013) and Timmer et al. (2015) give detailed description of its compiling methodology: the World Input-Output Table (WIOT). In the country classification of World Input-Output Table, this paper retained China, India, Japan, South Korea, Taiwan, the United States, and the rest of the countries were merged into other countries, and finally the six major countries were analyzed. The carbon dioxide coefficient (C) is calculated by dividing the CO_2 emissions of each industry in each country of the 35 sectors in 2013 by the corresponding output value. First, calculate the product input coefficient matrix (D) of each country, and then use the D coefficient to calculate the (I-D)^(-1) matrix of domestic correlation table, and calculate the value-added rate (V), then finally perform empirical analysis. Since the Socio Economic Accounts in the WIOD database has not published the 2016 carbon dioxide coefficient data conforming to the new 56-sector classification, so the 56-sector coefficients were not corresponded to the 35-sector classification.

Methods

There are two main methods used to analyze the driving factors of carbon emission growth in the existing literature: Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) (Hoekstra and van den Bergh, 2003). Some scholars have summarized IDA (Ang, 1995, 2004; Xu and Ang, 2013); and SDA (Rose and Casler, 1996; Su and Ang, 2012). In this paper, based on the results of Liu et al. (2016) that carbon dioxide emissions are closely related to export production, the first is to understand the Input-output analysis (IOA), which is a method of accounting account presentation, and the model building method depends on the input-output table of the country or region. A country's input-output (IO) table shows the flow of inventory and services, while since IO tables have a clear showing of the life cycle of an industry, the relationship between producers and consumers is related to the production chain of entire economy. By taking into account the impact of the entire supply chain IOA, the EIO model is used to estimate specific emissions from trade, thus the estimation formula of CO_2 emissions from national-level export is as follows:

$$CO_{2exp} = \mathrm{C} \cdot (I-A)^{-1} \cdot \mathrm{e} \qquad \text{(Eq.1)}$$

where:
CO_{2exp} = Total carbon dioxide emissions representing the specific exports;
c = 1 × n rows of carbon dioxide emissions, which is the carbon dioxide emissions per unit of economic output;
A = Intermediate input of total output in the n × n input coefficient matrix with the division by sectors;
$(I-A)^{-1}$ = Leontief inverse matrix representing the complete induced output matrix produced by a unit;

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e = n × 1 rows of vectors representing exports.

According to the different views on supply chain, exports at the emissions sector level can be tracked from upstream to downstream $(D \rightarrow U)$ or from upstream to downstream $(U \rightarrow D)$:

$$CO_{2exp}^{D \rightarrow U} = \mathrm{C} \cdot (I - A)^{-1} \cdot diag(e) \quad \text{(Eq.2)}$$

$$CO_{2exp}^{U \rightarrow D} = diag(c) \cdot (I - A)^{-1} \cdot e \quad \text{(Eq.3)}$$

In the traditional IO theory, the above two different measures have their own economic explanations, and play different roles in economic analysis. $CO_{2exp}^{D \rightarrow U}$ indicates the carbon dioxide emissions emitted by all industries for exporting certain specific products. In other words, this measure can check the emissions from all the sectors directly or indirectly affected by domestic upstream supply chains. In contrast, $CO_{2exp}^{U \rightarrow D}$ represents the CO_2 emissions of a specific sector's specific export. That is to say, this measure depends on how to show the emissions from specific upstream sectors will affect the final exports of all downstream industries.

Finally, according to the definition, there is no difference between the two measures in CO_2 emissions at national level in terms of export. If we replace imported wealth goods with a ratio v of added value relative to output, to estimate the direct and indirect impact of exports on domestic added value. The following formula can be used to calculate the value-added ratio v of an export product (a 1 × n vector representing each value-added unit by sector). The so-called entity value-added (GDP) can also be estimated by:

$$GDP_{exp} = v \cdot (I - A)^{-1} \cdot \mathrm{e} \quad \text{(Eq.4)}$$

Further use of *Equations2* and *3* to represent the carbon indicator P as emission intensity of export entity can be defined as follows:

$$\mathrm{P} = CO_{2exp} / GDP_{exp} \quad \text{(Eq.5)}$$

This indicator that indicates the value-added export emissions per unit of a country can therefore be considered as a potential environmental cost for national trade. Display export value-added quotas at the industrial level in the same way:

$$GDP_{exp}^{D \rightarrow U} = v \cdot (I - A)^{-1} \cdot \mathrm{diag}(e) \quad \text{(Eq.6)}$$

$$GDP_{exp}^{U \rightarrow D} = diag(v) \cdot (I - A)^{-1} \cdot \mathrm{e} \quad \text{(Eq.7)}$$

In addition, according to *Equation 6*, the specific emissions of carbon intensity export at the industrial level are defined as follows:

$$P^{D \rightarrow U} = CO_{2exp}^{D \rightarrow U} // GDP_{exp}^{D \rightarrow U} = [c \cdot (I - A)^{-1} \cdot diag(e)] // [v \cdot (I - A)^{-1} \cdot diag(e)] \quad \text{(Eq.8)}$$

$$P^{U \rightarrow D} = CO_{2exp}^{U \rightarrow D} // GDP_{exp}^{U \rightarrow D} = c // v \quad \text{(Eq.9)}$$

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We define "//" as operational symbol of a vector division. It can be seen that the carbon intensity of carbon emissions depends on the input coefficient c and the value-added rate v of emissions from all upstream sectors when exporting a specific product, while the carbon emissions of specific sectors are based on the carbon intensity of the production sector (sector emissions/added values), showing that all exports are equal to the conventional definition.

Supposing based on production, the estimation of carbon dioxide emissions depends on the amount of energy used, regardless of the type of industry that uses it. In other words, if different types of industries burn the same amount of specific types of energy, the difference in energy efficiency of the enterprise will be reflected in the energy use per unit of output. This also means that if the traditional IO table does not introduce enterprise heterogeneity and does not change the estimate of production base, thus carbon dioxide emission estimates at the industrial or national level may be different. The use of traditional IO tables can lead to overestimation of CO_2 emissions from exports and underestimation of CO_2 emissions from domestic final demand, which is mainly because different types of companies have different market shares in traditional IO tables, and neglecting the heterogeneity of enterprises can lead to overestimation of carbon dioxide emissions from exports.

Therefore, this paper replaces the $(I - A)^{-1}$ matrix with the $(I - A)^{-1}$ matrix, where $(I - A)^{-1}$ indicates the direct plus indirect domestic demand coefficient matrix, also known as the domestic industrial correlation matrix. The domestic industrial correlation matrix $(I - A)^{-1}$ is conducted with the sum of vertical and horizontal analysis to obtain the forward and backward correlation degrees of each industry. If the forward and backward correlation degrees are normalized, sensitivity and influence can be obtained. Industries with high forward correlation (sensitivity greater than one) are easy to support downstream industrial production by providing products for downstream industries. Industries with high backward correlation (influence degree greater than one) are easy to drive the development of other upstream industries, and the demand for upstream industrial products is higher. Industries with both high forward and backward correlation degrees as the important industries can drive the development of other industries. Industries with high forward correlation degree and low backward correlation degree can provide the cooperation for the development of other industries. Industries with low forward correlation degree and high backward correlation degree can drive the development of other industries and are not easily affected by other industries. Industries with both low forward and backward correlation degrees are the industries that are not susceptible to other industries and will not drive the development of other industries.

Results

Main empirical results

This paper collects data from the new version of WIOD (2000-2014) and the old version (1995-2011) to calculate CO_2 emissions, GDP and its intensity (the ratio of CO_2 emissions to GDP, that is, CO_2 emissions per unit of GDP driven by exports) driven by the total exports of major countries (see *Figs. 1* and *4*), the intermediate goods (see *Figs. 2* and *5*) and final goods (see *Figs. 3* and *6*).

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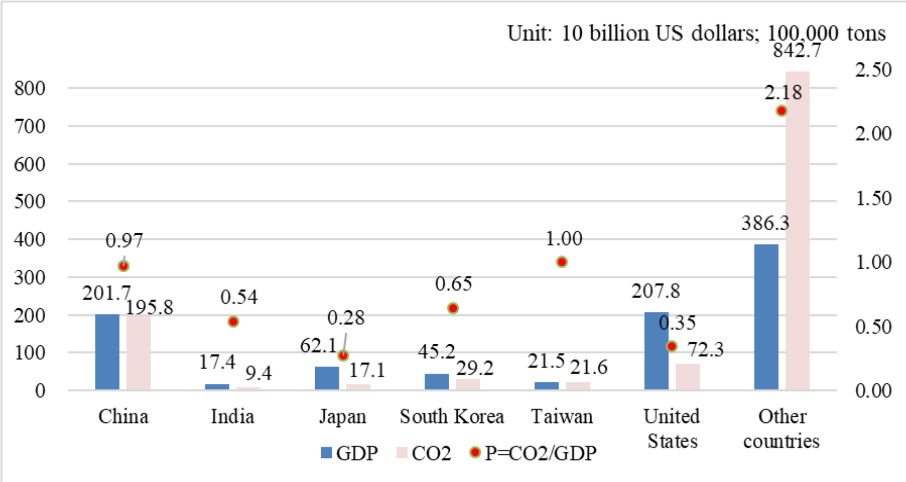

Figure 1. CO_2 *emissions, GDP and its intensity driven by total exports of countries in 2014 (new version)*

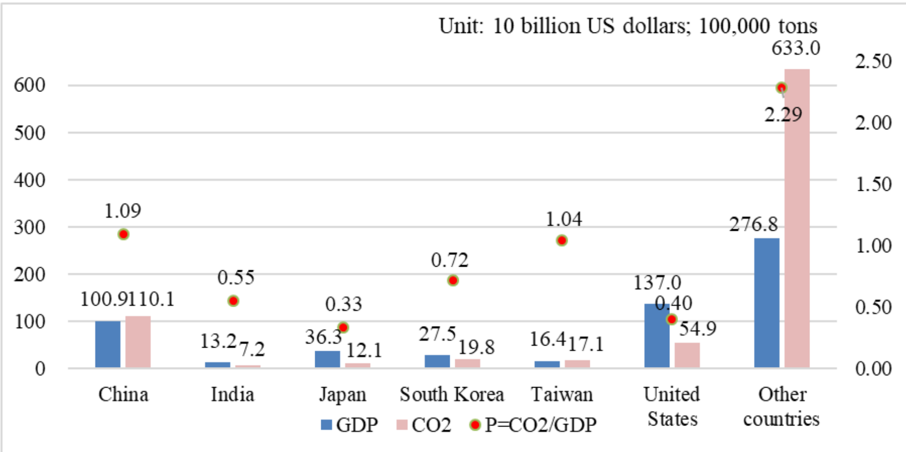

Figure 2. *CO_2 emissions, GDP and its intensity driven by intermediate goods exports of countries in 2014 (new version)*

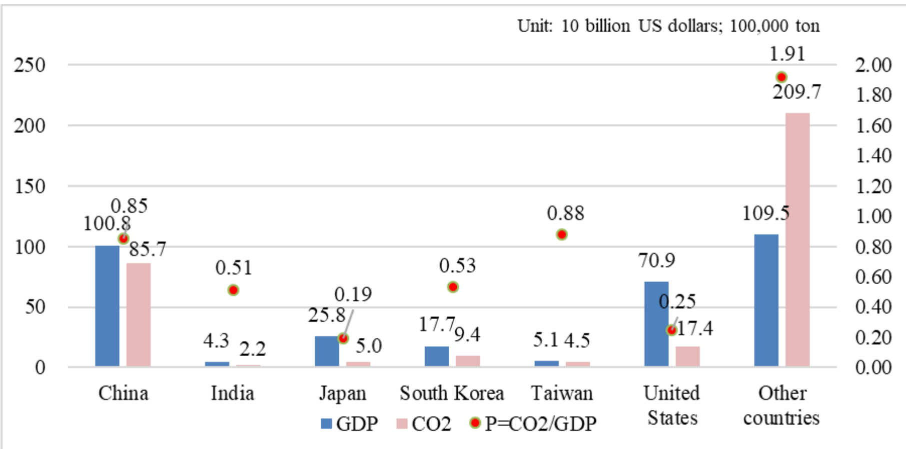

Figure 3. *CO_2 emissions, GDP and its intensity driven by final goods exports of countries in 2014 (new version)*

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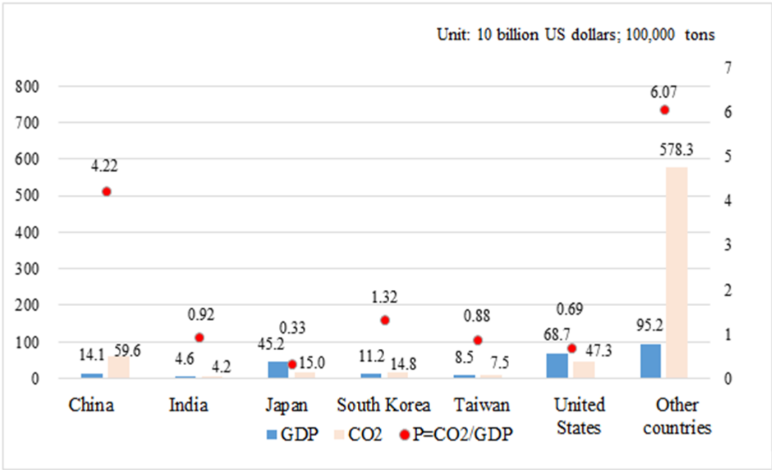

Figure 4. *The export level and intensity of total CO_2 emissions and GDP in 1995 (old version)*

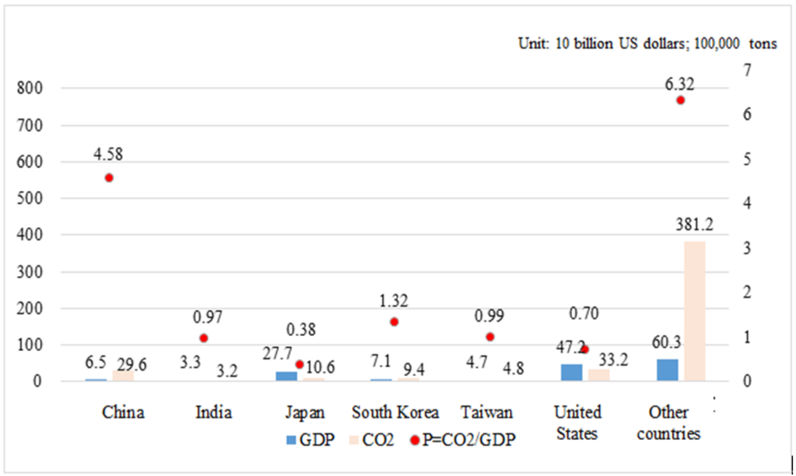

Figure 5. *The export level and intensity of total CO_2 emissions and intermediate goods-driven GDP in 1995 (old version)*

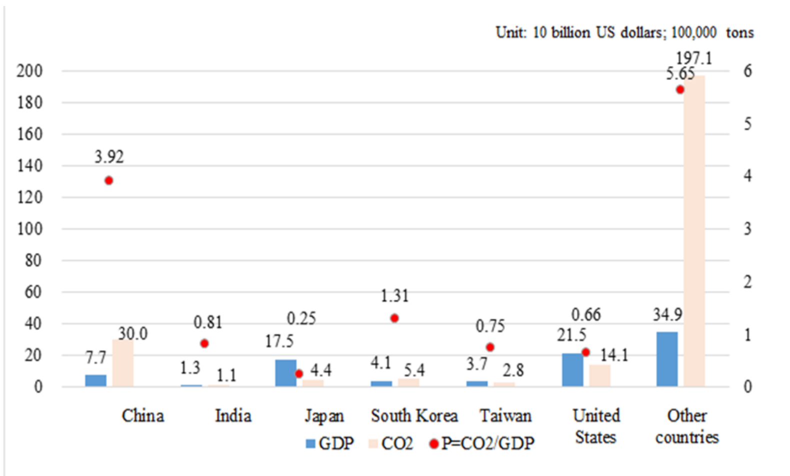

Figure 6. *The export level and intensity of total CO_2 emissions and final goods-driven GDP in 1995 (old version)*

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Figure 1 shows the CO_2 emissions, GDP and its intensity driven by total exports of countries in 2014 (new version). China ranks second with CO_2 emission intensity of 0.97 in various countries, including CO_2 emissions of 19.58 billion tons. *Figures 2* and *3* show that the CO_2 emission intensity of 1.09 driven by China's intermediate goods is greater than the CO_2 emission intensity of 0.85 driven by China's final goods, indicating that China's CO_2 emissions mainly come from the intermediate goods. Taiwan's CO_2 emission intensity driven by total exports is the highest, reaching 1.0, but in fact, Taiwan's CO_2 emissions are only 2.1 billion tons, because Taiwan's GDP is only 200 billion US$, only higher than the last ranking of India's 170 billion US$. *Figures 2* and *3* show that the CO_2 emission intensity of 1.04 driven by Taiwan's intermediate goods is greater than the CO_2 emission intensity of 0.88 driven by Taiwan's final goods, indicating that Taiwan's main CO_2 emissions come from the intermediate goods, and intermediate goods and final goods show a ratio of 3:1, showing that Taiwan is an economy that exports intermediate goods. South Korea, which is similar to Taiwan's industrial pattern, ranks third in terms of its CO_2 emission intensity of 0.65 driven by total exports, and its CO_2 emissions of 2.9 billion tons is only 800 million tons more than Taiwan, but its GDP is 450 billion US$. *Figures 2* and *3* show that the CO_2 emission intensity of 0.72 driven by South Korea's intermediate goods is greater than the CO_2 emission intensity of 0.53 driven by South Korea's final goods, indicating that South Korea's main CO_2 emissions mainly come from the intermediate goods. Japan's CO_2 emission intensity driven by total exports is the lowest, with CO_2 emissions of only 1.7 billion tons, but GDP is as high as 620 billion US$, which is three times that of Taiwan. The CO_2 emission intensity of 0.33 driven by Japan's intermediate goods is greater than the CO_2 emission intensity of 0.19 driven by Japan's final goods, indicating that Japan's CO_2 emissions mainly come from the intermediate goods.

Figure 4 shows the level and intensity of CO_2 emissions and GDP total exports in 1995 (old version). China's CO_2 emission intensity is 4.22, which is three times that of South Korea ranking the second, and China's CO_2 emissions are 5.9 billion tons, which ranks the first in the six countries, but China's GDP is only 140 billion US$, only 30 billion US$ higher than South Korea. *Figures 4–6* show that the CO_2 emission intensity of 4.58 driven by China's intermediate goods is greater than the CO_2 emission intensity of 3.92 driven by China's final goods, indicating that in 1995, China was still an intermediate goods-oriented country. Taiwan's CO_2 emission intensity is 0.88, ranking the fourth among the six countries, with CO_2 emissions of 700 million tons and GDP of 80 billion US$. The CO_2 emission intensity of 0.99 driven by Taiwan's intermediate goods is greater than the CO_2 emission intensity of 0.75 driven by Taiwan's final goods, indicating that in 1995, Taiwan was still an intermediate goods export-oriented country. South Korea's CO_2 emission intensity is 1.32, ranking the second among the six countries, with CO_2 emissions of 1.4 billion tons and GDP of 110 billion US$. *Figures 5* and *6* show that the CO_2 emission intensity of 1.32 driven by South Korea's intermediate goods is much the same as the CO_2 emission intensity of 1.31 driven by South Korea's final goods, indicating that in 1995, South Korea's export is complemented by intermediate goods and final goods. Japan's CO_2 emission intensity of 0.33 is almost the same as that of 2014, with CO_2 emissions of 1.5 billion tons and GDP of 450 billion US$. *Figures 5* and *6* show that the CO_2 emission intensity of 0.38 driven by Japan's intermediate goods is much the same as the CO_2 emission intensity of 0.25 driven by Japan's final goods, indicating that in 1995, Japan was an intermediate goods export-oriented country.

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Discussion

Analysis and comparison of export-driven CO_2 emission intensity in countries in 1995 and 2014

By comparing the level and intensity of CO_2 emissions and GDP driven by total exports of countries in 1995 and 2014 (see *Figs. 4* and *1*), we can see the rankings of CO_2 emission intensity in 1995 were: China, South Korea, India, Taiwan, the United States and Japan; rankings in 2014 were: Taiwan, China, South Korea, India, the United States and Japan. Taiwan rose from the fourth place to the first place, China, South Korea, and India all ranked down, and the United States and Japan ranked the same. In most countries, the level of CO_2 emissions has declined, except for Taiwan, and Japan which has low intensity. It has shown that Taiwan has grown with the same proportions of CO_2 and GDP in the past 20 years, but other developed countries have doubled.

Analysis of export-driven CO_2 emission paths

In order to concrete our results, *Figures 7–10* compare the CO_2 emissions in each industry and *Table 2* list the industry category and the definition. If we track from downstream industry to the upstream industry (D→U), and from upstream to downstream (U→D), the CO_2 emissions driven by the export of each country are observed, and the carbon dioxide emission paths of the industries in Taiwan are organized, as shown in *Figures 7* and *8*, where, $CO_{2exp}^{D\to U}$ indicates the carbon dioxide emissions emitted by all industries exporting specific products, which can be used to check the emissions of all sectors directly or indirectly affected by the domestic upstream supply chain, while $CO_{2exp}^{U\to D}$ indicates the carbon dioxide emissions emitted by specific exports from particular sectors, and it can show how the emissions from specific upstream sectors affect the final exports of all downstream industries.

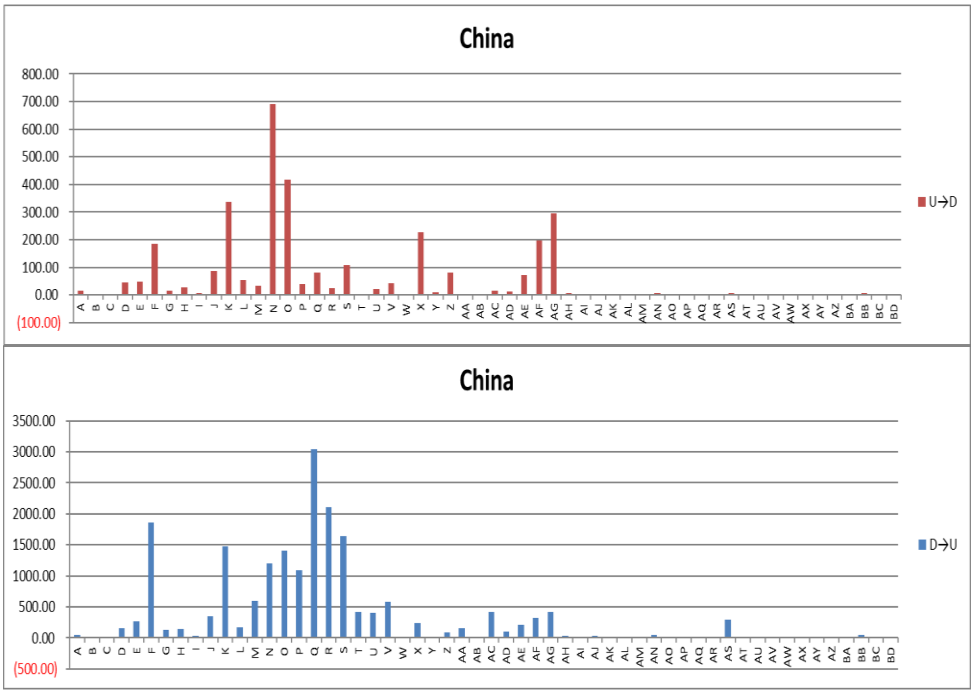

Figure 7. *CO_2 emissions driven by China's exports in 2014: tracking from the downstream industry to the upstream industry (D→U) and from upstream to downstream industry (U→D)*

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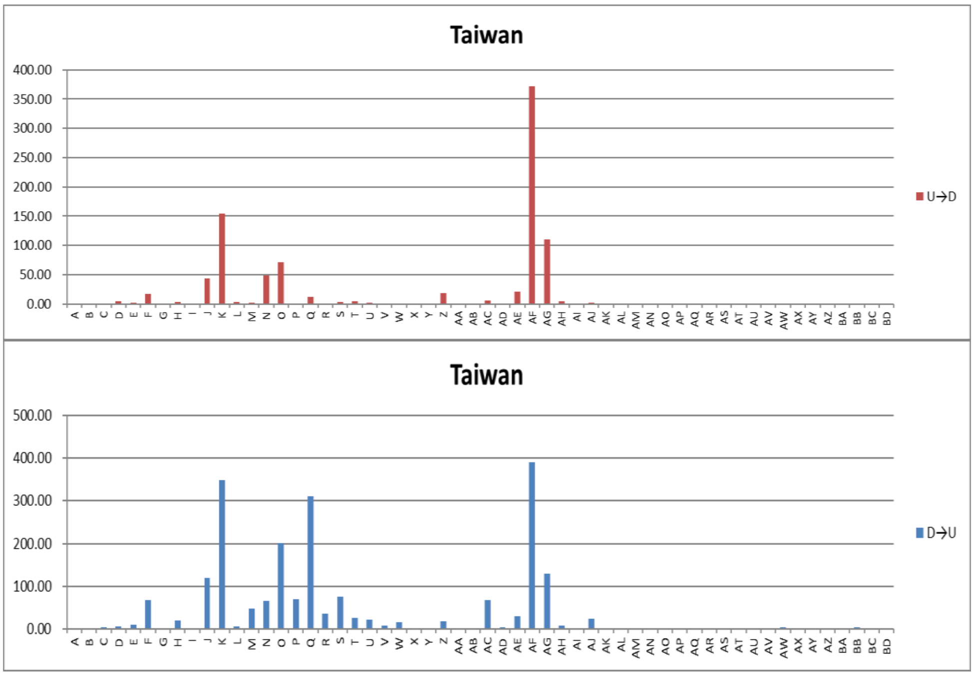

Figure 8. *CO_2 emissions driven by Taiwan's exports in 2014: tracking from the downstream industry to the upstream industry (D→U) and from upstream to downstream industry (U→D)*

Table 2. *Industry category and the definition in Figures 7–10*

Category	Definition
A	Crop and livestock products
B	Forestry logging
C	Fishing aquaculture
D	Mining
E	Food and beverage
F	Textile and apparel
G	Wooden products
H	Paper products
I	Print and copy
J	Coal petroleum products
K	Chemical products
L	Drug products
M	Rubber plastic products
N	Non-metallic mineral products
O	Metal products
P	Metal products (except equipment)
Q	Electronic optical products
R	Electrical equipment manufacturing
S	Transportation equipment manufacturing
T	Car trailer manufacturing
U	Mechanical equipment manufacturing
V	Furniture manufacturing
W	Mechanical equipment repair and installation

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X	Electricity-fired fluorine air conditioner supply
Y	Water collection and treatment supply
Z	Waste recycling management
AA	Construction
AB	Trade and repair of automobiles and locomotives
AC	Wholesale trade (except automobiles and locomotives)
AD	Retail (except automobiles and locomotives)
AE	Land pipeline transportation
AF	Water transport
AG	Air transport
AH	Warehousing and transportation
AI	Post Express
AJ	Accommodation activities
AK	Publishing
AL	Audio and video production and publishing
AM	Telecommunications
AN	Computer program consulting related
AO	Financial services (excluding insurance)
AP	Insurance (except compulsory insurance)
AQ	Financial and insurance assistance
AR	Real estate
AS	Legal and accounting advice related
AT	Construction engineering analysis
AU	Scientific research development
AV	Advertising and market research
AW	Other science and technology related to veterinary counseling
AX	Administrative service related
AY	Public administration and compulsory insurance
AZ	Education
BA	Health and social activities
BB	Other social activities
BC	Family (for domestic use)
BD	Related activities of overseas institutions
BE	Leather product

As shown in *Figures 4–7*, the CO_2 emissions driven by China's exports are tracked from the downstream industry to the upstream industry (D→U), that is, CO_2 emissions produced from the input of upstream industry because of the other industries driven by export products, see left bar of *Figures 4–7*. China's major downstream export industry sectors are electronic optical products (300 million tons), electrical equipment manufacturing (210 million tons), textile and apparel (180 million tons), transportation equipment manufacturing (160 million tons). The CO_2 emissions driven by China's exports are tracked from the upstream industry to the downstream industry (U→D) to track the upstream industry, which is to support the CO_2 emissions generated by the downstream industries, see the right bar of *Figures 4–7*. The upstream-supported export

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industry sectors are mainly non-metallic mineral products (70 million tons), metal products (40 million tons), and chemical products (30 million tons).

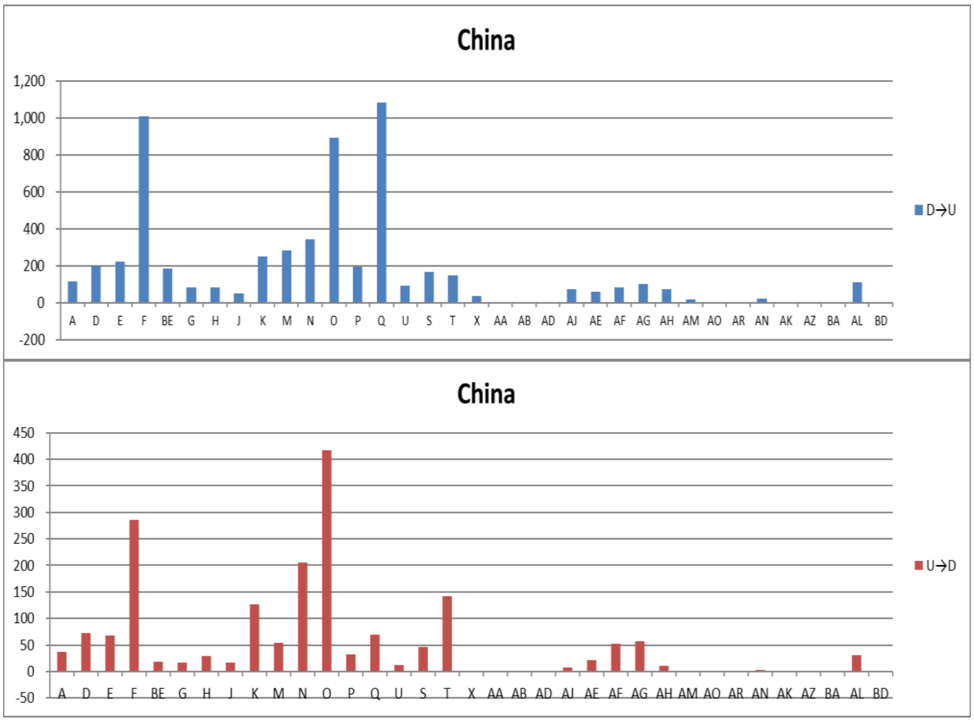

Figure 9. *CO_2 emissions driven by China's exports in 1995: tracking from the downstream industry to the upstream industry (D→U) and from upstream to downstream industry (U→D)*

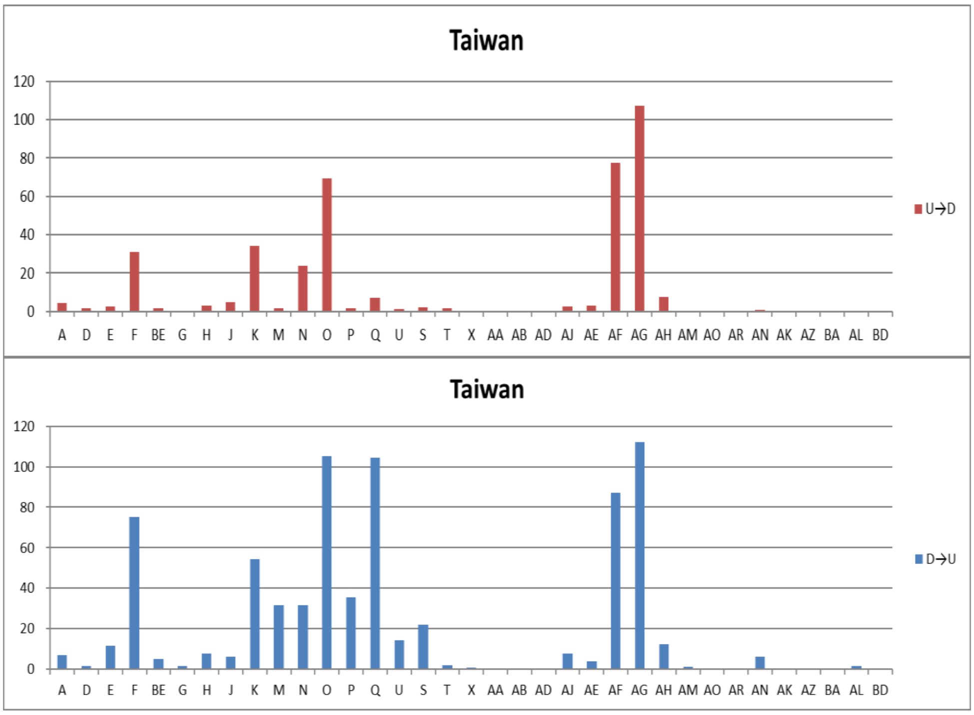

Figure 10. *CO_2 emissions driven by Taiwan's exports in 1995: tracking from the downstream industry to the upstream industry (D→U) and from upstream to downstream industry (U→D)*

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The CO_2 emissions driven by Taiwan's exports are tracked from the downstream industry to the upstream industry (D→U), see the left bar of *Figures 4–8*. The major downstream export industry sectors are water transport (about 39 million tons), chemical products (about 35 million tons), and electronic optical products (about 31 million tons). The CO_2 emissions driven by Taiwan's exports tracked from upstream industry to downstream industry (U→D) is shown in the right bar of *Figures 4–9*. The major industrial sectors invested in the upstream are water transport (about 37 million tons), chemical products (about 15 million tons), and air transport (about 11 million tons).

Finally, *Figures 9* and *10* summarize the estimated estimation on CO_2 emissions in China and Taiwan in 1995. The CO_2 emissions driven by exports from 1995 to 2014 are compared and tracked from the downstream industry to the upstream industry (D→U) and from upstream to downstream industry (U→D) see from *Fig 4- Fig 10.* In the CO_2 emissions driven by China's exports tracked from the downstream industry to the upstream industry (D→U), electronic optical products, textile and metal products have the most emissions, while when tracking from upstream to downstream industry (U→D), the metal products, textile and non-metal products have the most emissions. In 2014, China's major downstream industrial sectors added more high CO_2 emissions sectors such as electrical equipment manufacturing, transportation equipment manufacturing and chemical products. In 1995, when CO_2 emissions driven by Taiwan's exports are tracked from the downstream industry to the upstream industry (D→U), the air transport, metal products and electronic optical products have the most emissions, while when tracking from upstream to downstream industry (U→D), the air transport, water transport and metal products have the most emissions. In 2014, Taiwan's high CO_2 emissions sectors are water transport, chemical products and electronic optical products.

Conclusion

The composition of industrial chains is interdependent in international trade. Today, global trade belongs to different countries in the upper, middle and lower reaches of production process of vertical labor division. This paper analyzes trade items and supply chain portfolios from global value chains, and further integrates and compares the carbon emissions from supply chain portfolios across countries. Based on the results of Liu et al. (2016), this paper uses the EIO model to analyze the relationship between trade exports and carbon dioxide emissions in Taiwan and other six countries. The empirical analysis of this paper first analyzes the CO_2 emission intensity driven by countries' exports, where Taiwan's total CO_2 emission intensity is 1.0, topping the highest, with CO_2 emissions of only 2.1 billion tons, which is caused by Taiwan's low GDP of 200 billion US$. The CO_2 emission intensity driven by China's total exports is 0.97, with CO_2 emissions of as high as 19.58 billion tons, but the GDP is 2 trillion US$, resulting in an intensity of only 0.97. The CO_2 emission intensity driven by the US total exports is only 0.35, with CO_2 emissions of 7.2 billion tons, which is caused by the high US GDP as much as 2.07 trillion US$. South Korea, which is similar to Taiwan's industrial pattern, has a CO_2 emission intensity of 0.65 driven by its total exports, with CO_2 emissions of 2.9 billion tons, only 800 million tons more than Taiwan, but the GDP is 450 billion US$. The total CO_2 emission intensity driven by Japan's total exports is 0.28, with CO_2 emissions of only 1.7 billion tons, but the GDP is as high as 620 billion

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US$, which is three times that of Taiwan. The results of the analysis show that most developed countries take intermediate goods as the main export type under the global industrial chain, while the exports in less developed countries such as India have a ratio of 1:1 between intermediate goods and final goods, and final goods may even count greater than intermediate goods.

By comparing the level and intensity of CO_2 emissions and GDP total exports in various regions in 1995 and 2004, we can see that Taiwan rose from the fourth to the first place. China, South Korea and India ranked from the first, second and third to second, third and fourth, respectively, the United States and Japan remain unchanged at the fifth and sixth place. In most countries, the level of CO_2 emissions has declined, except for Taiwan, and Japan which has low intensity. It has shown that Taiwan has grown with the same proportions of CO_2 and GDP in the past 20 years, but other developed countries have doubled.

Then, if we track from downstream industry to the upstream industry (D→U), and from upstream to downstream (U→D), the CO_2 emissions driven by the export of Taiwan and mainland are observed, with CO_2 emissions produced from the input of upstream industry because of the other industries driven by China's downstream export products, which means that by tracking from downstream to upstream, China's major downstream export industry sectors are electronic optical products, electrical equipment manufacturing, textile and apparel and transportation equipment manufacturing. The upstream industry in China supports the CO_2 emissions generated by the downstream industries, that is, by tracing from upstream to downstream, the major upstream sectors supporting export industry are non-metallic mineral products, metal products and chemical products. Taiwan's major downstream export industry sectors are water transport, chemical products and electronic optical products, and the major upstream sectors are water transport, chemical products and air transport.

As China launches the carbon trading market, Singapore is expected to introduce a carbon tax in 2019, and many countries around the world have formulated a policy on carbon pricing. Yet it is uncertain whether the carbon tax will bring a huge burden to the economy, only some countries in northern Europe succeeded in maintaining economic growth rate. On the other hand, Australia has abolished the carbon tax, which became a major cause of dragging down the Australian economy. In Taiwan and other countries in the world, environmental mark and carbon footprint mark are more commonly used, that is, how much carbon is emitted from the product or how much energy is used in the product are clearly marked, so that consumers can choose whether to buy lower-carbon products after reading the message. Energy costs such as the use of fuel may rise from the imposition of emission taxes, while people can transform the society into a sustainable development pattern through the change of lifestyle. This paper is mainly to explore the generation and attribution of CO_2 generated by inter-regional economic production and exchange, and to compare the growth rate of CO_2 emissions between different economies. In the follow-up, we will further explore the relationship between environmental shocks, foreign trade changes, and commodity substitutions generated by such economic activities.

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REFERENCES

[1] Ang, B. W. (1995): Decomposition methodology in industrial energy demand analysis. – Energy 1: 168-182.

[2] Ang, B. W. (2014): Decomposition analysis for policy making in energy: which is the preferred method? – Energy Policy 32: 1131-1139.

[3] Dietzenbacher, E., Stage, J. (2006): Mixing oil and water? Using hybrid input-output tables in a structural decomposition analysis. – Economic Systems Research 18: 85-95.

[4] Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M. P., de Vries, G. J. (2013): The construction of world input-output tables in the WIOD Project. – Economic Systems Research 25: 71-98.

[5] Hoekstra, R., van den Bergh, J. M. (2003): Comparing structural decomposition analysis and index. – Energy Economics 25: 39-64.

[6] Jin, A. H., Bai, L., Kim, J. Y., Jeong, S. J., Kim, K. S. (2017): Analysis of GHG emission reduction in South Korea using a CO_2 transportation network optimization model. – Energies 10: 1-18.

[7] Kagawa, S., Inamura, H. (2001): A structural decomposition of energy consumption based on a hybrid rectangular input-output framework: Japan's case. – Economic Systems Research 13: 339-363.

[8] Lenzen, M. (2003): Environmentally important paths, linkages and key sectors in the Australian economy. – Structural Change and Economic Dynamics 14: 1-34.

[9] Lenzen, M., Pade, L. L., Munksgaard, J. (2004): CO_2 multipliers in multi-region input-output models. – Economic Systems Research 16: 391-412.

[10] Lin, C., Yang, J. (2017): Research on the Technology Spillover Effect of Taiwanese Investment on Agricultural Products Processing Industry in Mainland China. – In: 2017 International Conference on Education Science and Economic Management (ICESEM 2017). Atlantis Press, Paris.

[11] Liu, Y., Mong, B., Hubacek, K., Xue, J., Feng, K., Gao, Y. (2016): Made in China: a reevaluation of embodied CO_2 emissions in Chinese exports using firm heterogeneity information. – Applied Energy 184: 11106-1113.

[12] Lu, M. (2018): Introduction: The Changing Geographies of China. – In: Li, S. et al. (eds.) Changing China. Routledge, Abingdon, pp. 1-13.

[13] Meng, B., Fang, Y., Guo, J., Zhang, Y. (2017): Measuring China's domestic production networks through trade in value-added perspectives. – Economic Systems Research 29(1): 48-65.

[14] Peter, G. P., Hertwich, E. G. (2006): Structural analysis of international trade: environmental impacts of Norway. – Economic Systems Research 18: 155-181.

[15] Rigger, S. (2015): Taiwanese Business in Mainland China: From Domination to Marginalization? – In: Irwin Crookes, P., Knoerich, J. (eds.) Cross-Taiwan Strait Relations in an Era of Technological Change (pp. 61-76). Palgrave Macmillan, London.

[16] Ritchie, H., Reay, D., Higgins, P. (2018): Sustainable food security in India—Domestic production and macronutrient availability. – PloS One 13(3): e0193766.

[17] Rose, A., Casler, S. (1996): Input-output structural decomposition analysis: a critical appraisal. – Economic Systems Research 8: 33-62.

[18] Su, B., Ang, B. W. (2012): Structural decomposition analysis applied to energy and emissions: some methodological developments. – Energy Economics 34: 177-188.

[19] Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. de Vries, G. J. (2015): An illustrated user guide to the world input output database: the case of global automotive production. – Review of International Economics 23: 575-605.

[20] Xu, X. Y., Ang, B. W. (2013): Index decomposition analysis applied to CO_2 emission studies. – Ecological Economics 93: 313-329.

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