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An Analysis of CO_2 Emissions from International Transport and the Driving Forces of Emissions Change

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Received: 30 April 2018; Accepted: 19 May 2018; Published: 22 May 2018

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Abstract: As a consequence of globalization, increased international transport generates many pollutants. Pollution generation from other industries related to international transport also cannot be ignored. This paper thus aims to investigate the carbon emissions from international transport. We analyzed embodied carbon emissions of international transport using multi-region input output analysis, and identified the factors underlying changes in emissions using structural decomposition analysis. China was the world's largest CO_2-emitting country in international transport in terms of both production- and consumption-based standards. However, consumption-based emissions in that country were much lower than production-based emissions, while in the United States, with second largest emissions, the situation was the opposite. Major emission changes were contingent on demands for international transportation and emission efficiency. In the case of the European Union (EU), consumption-based emissions were higher, but CO_2 emissions decreased gradually due to increased emission efficiency. The different information is provided by each standard, and reduction targets can change according to the standards employed. While discussions on emissions standards are still in progress, the results of this study suggest that CO_2 emissions from international transport, and according to different emissions standards, should receive careful attention in energy policy design, in order to limit CO_2 emissions globally.

Keywords: international trade; CO_2 emission; input output analysis; structural decomposition analysis; embodied carbon

1. Introduction

We are experiencing significant impacts of climate change, and attempts to address this problem are being made all over the world. The Paris agreement is part of this effort; it concluded in 2015 and calls for efforts to address climate change in 194 countries around the world. The agreement deals with the long-term goals of all parties, financial flows, technological problems, and supporting actions to start in the year 2020 [1]. Among the six kinds of greenhouse gases (GHG), CO_2 contributes the largest portion to the greenhouse effect, at about 56% [2]; one of the main goals in the agreement is the global reduction of CO_2 emissions. Many parties to the Convention on Climate Change have formed action plans to set their own reduction targets and reduce CO_2 emissions. Prior to these efforts, accurate measurement of emissions is the starting point for proper policy implementation. Despite these facts, however, there has been a lack of discussion on the carbon emissions from international transport.

As a consequence of globalization, international trade has significantly increased over the past decade. As international trade has grown, international transportation service volumes have also increased sharply. The values of mercantile trade and trade in commercial services in 2015 were

16,500 billion USD and 2700 billion USD respectively, nearly twice as high as in 2005 [3]. International trade involves not only the movement of goods; international transport via air, sea, and land also generates much carbon emissions, and many studies mention that the emissions from international transport are significant. According to Buhaug et al. [4], CO_2 emissions from international shipping were 870 million tons in 2007. Cristea et al. [5] reports that "International transport is responsible for 33% of world trade related emissions, and over 75% of emissions for major manufacturing categories". Despite the proposed guidelines by the International Maritime Organization (IMO) or other organizations for carbon taxes and cap-and-trade schemes, emissions from the maritime and aviation sector increased by 64% and 90% in 2013, respectively, compared to 1990 [6]. It is expected that the CO_2 emissions of maritime transport will increase by 150~250% [4].

Another international issue related to global emissions is carbon leakage. Developed countries, in line with the goal of reducing emissions under international agreement, are willing to reduce their carbon-intensive industries and outsource the carbon-intensive products; however, developing countries will still have to attract carbon-intensive industries for economic development. As a result, carbon leakage provides a mechanism by which those industries that produce a lot of pollutants can move to countries with fewer environmental regulations [7]. There is only a change in the area where carbon is emitted, and the global emissions do not decrease. Therefore, some argue that the responsibilities of the countries that import carbon intensive goods should be shared with the countries that supply them. However, currently the most widely-used territorial-based emissions do not address this problem. Carbon leakage problems can be analyzed through consumption-based emissions analysis, and there have been continuous arguments that consumption-based emissions, as well as production-based emissions, should be included in national CO_2 emissions estimates. Our research on carbon emissions from international trade is ultimately aimed at clarifying such responsibilities and finding ways to reduce carbon emissions globally.

Energy-related carbon embodied in trade, using input–output analysis, have been widely studied. Machado et al. [8] analyzed the impacts of Brazil's international trade on that country's energy use and CO_2 emissions using input–output techniques. They showed that the energy embodied in the export of non-energy goods is larger than the energy embodied in the imports. Julio and Rosa [9] evaluated Spain's exports and imports in terms of embodied CO_2 emissions. They identified whether an industry is carbon-import or -export industry. Nobuko [10] examined the major factors affecting CO_2 emissions produced by industries in Japan between 1985–1995, using input–output analysis. The results showed that the effects of environment-technological and production-technological changes contributed to decreases in CO_2 emissions. Peters and Hertwich [11] identified the CO_2 emissions embodied in international trade for 87 countries for the year 2001. They emphasize the importance of considering embodied carbon in trade and propose several policy implications from their findings. Lin and Sun [12] analyzed China's CO_2 emissions from exports and imports. Based on the results, they revealed that the production-based emissions were larger than consumption-based emissions, which is evidence that carbon leakages occurs under the current climate policies and international trade rules.

The ultimate goal of research on carbon emissions is to reduce carbon emissions globally, and many studies have thus investigated the factors that increase CO_2 emissions using a decomposition analysis. A decomposition analysis is used to identify and assess the factors in order to analyze and understand changes in socioeconomic indicators [13]. A structural decomposition analysis (SDA), which is used to study changes at a given level by analyzing direct and indirect effects, has also been used to identify the key factors of energy and CO_2 emission changes for multiple countries and regions. Xie [14] examined the driving force of China's energy use in the period 1992–2010, and the results indicated that Chinese energy use was mainly driven by investment-led demand. Zhang and Lahr [15] analyzed the key factors of energy consumption change in China from 1987–2007. They found that the changes from input structure and consumption structure increased energy use. Wang et al. [16] analyzed the driving forces for the change in CO_2 emissions in the city of Beijing from both production and final demand perspectives over 1997–2010. According to the results, the

CO_2 emission growth in Beijing was driven mainly by production structure changes and population growth. The emission was partly offset by the decline of CO_2 emission intensity and per capita final demand. A number of studies on energy consumption and pollution generation in China have been conducted [17–21]. For the United States, Rose and Chen [22] analyzed the changes in CO_2 emissions over the 1972–1982 timeframe. They revealed that economic growth, KLEM (Capital, Labor, Energy, and Material) substitution, and the joint effects of technological change were the major sources of upward pressure on energy use, while energy conservation and a technological change in materials were the sources of energy use decrease. Weber [23] analyzed changes of energy usage and flows in the United States between 1997 and 2002 using SDA. They found that population growth and household consumption acted to drive up energy demand, but this driving force was offset by a structural change within the economy. Feng et al. [24] analyzed the factors affecting U.S. emissions from 1997–2013. The results showed that the changes of emissions were primarily driven by economic growth and fuel mix. For Singapore, Su et al. [25] investigated the key driving factors of emission changes during the period 2000–2010. Cansino et al. [26] deconstructed the changes in CO_2 emissions at the sectoral level in Spain for the period 1995–2009. Based on the results, they suggested policies against climate change. Chang et al. [27] examined the changes in CO_2 emissions in Taiwan from 1989–2004. For multiple regions, Xu and Dietzenbacher [28] studied the driving forces behind the growth of carbon emissions embodied in trade in 40 countries during 1995–2007. Wang et al. [29] studied changes in CO_2 emission intensities for three major economies—China, India, and the United States—from 2000–2009. In addition, various attempts have been made to reduce CO_2 emissions [30,31]. However, there is not much research focusing on emissions from international transport.

The purpose of this paper is to analyze CO_2 emissions from international transport, and to identify the factors underlying changes in emissions that are linked to international transport. In particular, we focus on emissions from the international transport of manufactured goods in global supply chains. Three different countries, as exporter, importer, and transporter, will be involved in CO_2 emissions from international transport, creating a difficult problem in assigning the proper responsibilities. In order to analyze them, we constructed a multi-regional input-output (MRIO) model, incorporating national input–output tables and data on trades. For MRIO, both the international trade structure and the country's production structure should be considered [32]. From the GTAP (Global Trade Analysis Project) database, a regional input–output table for MRIO analysis can be constructed. The GTAP database was originally based on the computable general equilibrium model, but we used it because it contains data that can be used to obtain MRIO. The above analysis method can be used to measure direct emissions of environmental pollutants and indirect emissions from intermediate materials. In order to investigate the factors of change, we used structural decomposition analysis based on input–output analysis. The contribution of this study is to analyze the CO_2 emissions from international transport services, attributed in each case to the three countries involved in terms of production standards and consumption standards, and to analyze the causes of the changes in emissions. There are a number of studies on emissions arising from trade engaged in by existing minor national economies, but this study covers more regions around the world with regard to CO_2 capture. The methods and results of these analyses are expected to affect future worldwide climate policy and international negotiations.

The rest of the paper is organized as follows. The methodology used in this study is described in Section 2. Section 3 presents the data and framework. Section 4 presents the results of calculating international transport emissions from production- and consumption-based models. In Section 5, the paper concludes with reflections on the contributions, discussions, and possible extensions of this work.

2. Methodology

2.1. Multi Regional Input–Output Analysis

An input–output matrix that expresses the global economy as a single input–output matrix is called an MRIO matrix. The coefficient matrix can be obtained by dividing the intermediate by the total output [33]. This form of MRIO is as follows:

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^m \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{MM} \end{pmatrix} \begin{pmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{pmatrix} + \sum_s \begin{pmatrix} y^{1s} \\ y^{2s} \\ \vdots \\ y^{ms} \end{pmatrix} + \begin{pmatrix} t^1 \\ t^2 \\ \vdots \\ t^m \end{pmatrix}, \quad (1)$$

where international transport is represented in the final demand.

If we divide the total CO_2 emissions of industry i by the total output of industry i, we obtain the unit of CO_2 emissions for industry i.

$$f_i = e_i / x_i, \quad (2)$$

where f_i is the CO_2 intensity of industry i's row vector. The first goal of this study is to measure CO_2 emissions from international transport, using production- and consumption-based measures. International transport services, such as international air, sea, and inter-country road transport, involve three countries in one service: the exporting, importing, and service-supporting countries of goods subject to international carriage. For the purpose of estimating the emissions incurred related to the export and import of goods, the exports of international transport services were allocated to those countries exporting products using these services, as well as the countries importing them.

Based on production standards, CO_2 emissions from international transportation are CO_2 emissions caused by countries that export products using international transportation services. When calculating using consumption standards, the assessment is that the importing country using international transportation services emits CO_2. The production-based CO_2 emissions of a given country can be obtained using the MRIO method, by summing the CO_2 emissions from the domestic production of final goods consumed in country r and the CO_2 emissions from producing the final goods exported from country r to other countries.

$$F_p = f'(I-A)^{-1}(t^{rr} + t^{rs}), \quad (3)$$

$$F_p = \begin{pmatrix} F_p^1 \\ F_p^2 \\ \vdots \\ F_p^r \\ \vdots \\ F_p^n \end{pmatrix}, \quad (4)$$

Consumption-based CO_2 emissions can be calculated as the sum of CO_2 emissions from domestic production of final goods consumed in the country and CO_2 emissions from final products imported from countries other than country r to country r.

$$F_c = f'(I-A)^{-1} \begin{pmatrix} t^{1r} \\ t^{2r} \\ t^{3r} \\ \vdots \\ t^{nr} \end{pmatrix}, \quad (5)$$

$$F_c = \begin{pmatrix} F_c^1 \\ F_c^2 \\ \vdots \\ F_c^r \\ \vdots \\ F_c^n \end{pmatrix}, \quad (6)$$

2.2. Structural Decomposition Analysis

The index decomposition analysis (IDA) and the structural decomposition analysis (SDA) methodologies are representative methods for analyzing change factors over time. IDA is based on index theory, whereas SDA is based on the theory of input–output analysis. Therefore, these two methods have developed independently [34]. According to Kim and Heo [35], SDA is a suitable way to identify the effects of structural changes in industries. In this study, the average SDA—which allows us to analyze driving factors in detail and include indirect effects—was employed. Leontief [36] initially proposed structural decomposition analysis, while Chenery et al. [37] first applied decomposition analysis based on economic theory. Rose and Chen [38] then attempted to extend the existing decomposition analyses by adding capital, labor, energy, and materials. In this study, by applying mid-point weights to the decomposition, we decomposed CO_2 emission change into three basic effects: intensity effect, Leontief effect, and final demand effect.

A country's CO_2 emissions TE are equal to the product of sector-specific emission intensity B, production induction coefficient G, and final demand Y. The CO_2 emissions from international transport between a base year (0) and a comparative year (1) can be expressed as follows:

$$\Delta TE = B^1G^1Y^1 - B^0G^0Y^0, \quad (7)$$

$$= \frac{1}{2}(\Delta BG^*Y^* + \Delta B(GY)^*), \quad (8)$$

$$+ B^*\Delta GY^*, \quad (9)$$

$$+ \frac{1}{2}(B^*G^*\Delta Y + (BG)^*\Delta Y), \quad (10)$$

where Equation (8) is the intensity effect, Equation (9) is the Leontief effect, and Equation (10) is the final demand effect. The above equations can be decomposed further; the energy intensity can be decomposed as follows:

$$\frac{1}{2}(\Delta BG^*Y^* + \Delta B(GY)^*), \quad (11)$$

$$= \frac{1}{2}\{(B^\# - B^0)G^*Y^* + (B^\# - B^0)(GY)^*\}, \quad (12)$$

$$+ \frac{1}{2}\{(B^1 - B^\#)G^*Y^* + (B^1 - B^\#)(GY)^*\}, \quad (13)$$

$$B^\# = \frac{\sum B^1}{\sum B^0}B^0, \quad (14)$$

Emissions intensity is divided into components Equations (12) and (13), where Equation (12) shows the effect of improving the emission intensity and Equation (13) shows the effect of changing the energy consumption structure. On the other hand, the impact of the change in final demand on the increase in carbon emissions can be expressed as follows:

$$\frac{1}{2}(B^*G^*\Delta Y + (BG)^*\Delta Y), \tag{15}$$

$$= \frac{1}{2}\{B^*G^*(F^\# - F^0) + (BG)^*\left(F^\# - F^0\right)\}, \tag{16}$$

$$+ \frac{1}{2}\{B^*G^*(F^1 - F^\#) + (BG)^*(F^1 - F^\#)\}, \tag{17}$$

$$F^\# = \frac{\sum F^1}{\sum F^0}F^0, \tag{18}$$

The final demand change effect is divided into Equation (16) final demand growth effect and Equation (17) final demand structure change effect.

$$\Delta \mathrm{TE} = 1/2\{(B^\# - B^0)G^*Y^* + (B^\# - B^0)(GY)^*\}, \tag{19}$$

$$+ 1/2\{(B^1 - B^\#)G^*Y^* + (B^1 - B^\#)(GY)^*\}, \tag{20}$$

$$+ B^*\Delta GY^*, \tag{21}$$

$$+ 1/2\{B^*G^*(F^\# - F^0) + (BG)^*(F^\# - F^0)\}, \tag{22}$$

$$+ 1/2\{B^*G^*(F^1 - F^\#) + (BG)^*(F^1 - F^\#)\}, \tag{23}$$

The first term on the right-hand side of the above equation represents changes in direct CO_2 emission intensities. The second term represents changes in the composition of energy sources. The third term represents changes in the production inducement coefficient, while the fourth term shows changes in final demand. The last term represents changes in final demand structure. Table 1 shows the driving factors and their meanings. All terms consider both direct and indirect influences on the CO_2 emissions in international transport.

Table 1. Driving factors and meaning.

Equation	Effects	Meaning
(19)	Effect of change in emission efficiency	Impact of changes in emission source unit on changes in emissions
(20)	Direct energy substitution effect	The impact on emissions due to the change in composition of energy sources under the same energy efficiency
(21)	Effects of input technology change (Leontief effects)	Effects of changes in production inducement coefficient on changes in emissions
(22)	Final demand growth effect	Impact of changes in final demand on emissions
(23)	Final demand structure change effect	Influence of changes in final demand structure on emissions

3. Data and Framework

The GTAP is a global network program, initiated in 1993 to provide the economic research community with a global economic dataset for use in the quantitative analyses of global economic issues. In order to construct an MRIO model, both the international trade structure and the country's production structure should be considered [34]. The GTAP dataset includes input–output tables for each country and a full set of international trade flows, with associated transport costs, export taxes, and tariffs. The most recently released GTAP version 9.0 was announced in 2014. In the GTAP 9.0, 2004, 2007, and 2011 data are provided as the reference years, and we used these. The GTAP database provide three types of price data: agent's price, market price, and world price. There is no price corresponding to the generally recommended basic price, and it is taken as the nearest market price.

We used the database first as the basis for the MRIO assessment of the direct and indirect carbon contents of goods produced in different countries. GTAP also provides data on CO_2 emissions from energy combustion. CO_2 emission data and total output from each region were obtained from the database and applied to analysis of CO_2 intensity. We then estimated the MRIO-based carbon emissions to evaluate the economic consequences of international trade. GTAP version 9.0 includes trade statistics for 140 countries and regions and 57 industries, as well as international trade data between countries. Input-output tables for each region were obtained from GTAP for the years 2004, 2007, and 2011. In order to analyze the change factors of the emissions using the SDA described above, the total period was divided into two sub-periods: 2004–2007 and 2007–2011.

In order to measure carbon emissions from international transport, regions and industries were reclassified for analytical purposes. The major countries related to China, which has the highest trade volume in the world, are categorized first, and the remaining countries are classified by continent. In the industrial classification, industries with similar tendencies were reclassified. Appendixs A and B show the 14 regions and 28 sectors that were reclassified. Production standards conform to producer responsibility, and consumption standards conform to consumer responsibility. Therefore, the production standard is based on the exporting country, and the consumption standard is based on the importing country.

4. Results

4.1. Carbon Emissions from International Transport

First, looking at the exports of international transport services in the regions classified, the European Union (EU) provides the most international transportation services during the analysis period (Table 2). The EU accounts for more than 40% of transportation services, while Japan accounts for 9–10%, and Korea 7%. In other words, the EU emits the most pollutants as a transporter that carries goods directly. China's share seems to be gradually increasing, from about 4% in 2004 to about 7% in 2007 and 2011. The total exports of international transportation services increased significantly between 2004 and 2007. Although the EU provides the most international transport services, this study has allocated emissions to the regions directly exporting and importing products using international transport services, since the purpose of this study is to estimate the emissions associated with the import and export of products.

Table 2. International transportation services of each country (million USD, %).

Region	2004	2007	2011	2004	2007	2011
1 Oceania	2155	2885	4107	0.58%	0.53%	0.53%
2 Jpn	37,795	50,508	71,768	10.1%	9.29%	9.25%
3 Hkg	10,849	15,316	21,796	2.93%	2.82%	2.81%
4 Chn	13,625	37,156	52,812	3.68%	6.84%	6.81%
5 Kor	26,017	39,082	55,617	7.03%	7.19%	7.17%
6 Twn	2931	3769	5038	0.79%	0.69%	0.65%
7 RAsia	29,459	48,464	68,974	7.96%	8.92%	8.89%
8 USA	23,416	28,487	40,586	6.33%	5.24%	5.23%
9 NAmerica	5704	6931	9860	1.54%	1.28%	1.27%
10 LatinAmer	7704	10,777	15,259	2.08%	1.98%	1.97%
11 EU_28	164,482	233,232	331,739	44.4%	42.9%	42.7%
12 ME	13,065	20,873	32,547	3.53%	3.84%	4.19%
13 Af	4347	6680	9589	1.17%	1.23%	1.24%
14 Restofworld	28,591	39,399	56,336	7.72%	7.25%	7.26%

Based on the above model, we analyzed the carbon emissions embodied in international transport, in both production- and consumption-based terms. The total CO_2 emissions for each region in 2004, 2007, and 2011 were estimated, and are presented as follows. In Table 3, production-based CO_2 emissions were estimated according to Equation (3), and consumption-based CO_2 emissions were calculated in Table 4 from Equation (5).

Table 3. Production-based carbon emissions (mt).

Region	2004	2007	2011
1 Oceania	5.5082	6.0475	7.5457
2 Jpn	2.4120	2.7177	2.2226
3 Hkg	0.0007	0.0010	0.0010
4 Chn	86.9821	98.2972	93.8757
5 Kor	2.2590	2.6974	1.7785
6 Twn	1.6855	1.2735	0.9784
7 RAsia	33.0833	32.4318	34.8305
8 USA	15.0874	17.4830	22.9491
9 NAmerica	6.0097	13.3494	14.6392
10 LatinAmer	12.8534	17.1971	15.8952
11 EU_28	14.2243	11.7241	10.4321
12 ME	13.5493	12.4280	15.8691
13 Af	9.0980	8.4970	8.4119
14 RestofWorld	28.5628	26.5035	26.26885
TOTAL	231.3162	250.6487	255.6983

Table 4. Consumption-based carbon emissions (mt).

Region	2004	2007	2011
1 Oceania	4.4983	3.7109	3.7379
2 Jpn	3.0407	6.3848	5.4219
3 Hkg	0.0049	0.0030	0.0033
4 Chn	65.7920	73.9260	90.4700
5 Kor	2.1598	6.6303	4.0619
6 Twn	1.1591	0.9463	0.7603
7 RAsia	29.6541	31.6454	40.7864
8 USA	26.2632	29.6941	29.2591
9 NAmerica	5.5099	9.7618	10.2574
10 LatinAmer	7.4862	7.5277	8.2096
11 EU_28	17.7656	14.0115	12.3092
12 ME	16.0711	15.5795	18.8432
13 Af	10.2460	10.6698	11.1921
14 RestofWorld	21.3447	22.9550	21.1098
TOTAL	210.9965	233.4471	256.4229

With regards to production-based CO_2 emissions, China produced the most, at 87 million tons (mt) in 2004. China accounts for about 38% of total emissions. The next regions that appeared to emit considerable amounts of CO_2 are the rest of Asia (about 33 mt), the United States (15 mt), the EU (14 mt), and the Middle East (14 mt), apart from the rest of the world at 29 mt. In 2004, total CO_2 emissions from international transport were 231 mt. In 2007, China also had the largest CO_2 emissions, up about 11 mt from the previous year to 98 mt. The rest of Asia and the United States produced 32 mt and 17 mt, respectively, while Latin America and North America produced 17 mt and 13 mt, respectively, with a significant increase in emissions from the previous year. On the other hand, the Middle East and EU regions decreased by about 12 mt compared with the previous year. As a single country, the United States has the second highest emissions after China. Total emissions increased by 19 mt compared with the previous year, to about 250 mt of CO_2. In 2011, total CO_2 emissions increased by a relatively small amount to 255 mt. China's emissions were still high, but decreased by about 4 mt compared with the previous year, reaching 93 mt. In addition, emissions from the rest of Asia, the United States, the Middle East, and North America increased, but Latin America decreased their emissions. The EU's emissions also declined, suggesting that overall emissions are declining during the analysis period. Looking at the trends in total emissions, these increased by about 19 mt in 2004–2007, but increased by about 5 mt in 2007–2011. Discussions on the change factors of emissions is covered in the next section.

Consumption-based emissions are also the highest in China, accounting for more than 50%, with the rest of Asia and the United States following. China produced CO_2 emissions of 65 mt from international transportation in 2004. This result is much smaller than China's production-based emissions over the same period. It increased sharply until 2011, reaching 90 mt, which is a similar level to the production-based emissions. The rest of Asia also showed the second-highest CO_2 emissions, at 30 mt in 2004 and increasing to 41 mt in 2011. On the other hand, the EU shows a trend of decreasing CO_2 emissions. In 2004, the EU produced emissions of about 18 mt, falling to 14 mt in 2007 and 12 mt in 2011. In other areas, fairly constant levels of CO_2 were emitted during the analysis period. Both total emissions and production-based emissions increased during the analysis period. Total consumption-based CO_2 emissions from international transport were 210 mt in 2004, 233 mt in 2007, and 256 mt in 2011.

When we look at the major emitting regions according to production- and consumption-based standards, we should focus on China and the United States, which are the first- and second-highest CO_2-emitting countries. China has less consumption-based emissions than production-based, and the United States has more consumption-based than production-based emissions. This is because in China, the use of international transportation to produce and export goods is greater than the use to make imports, whereas in the United States the situation is the opposite. China is a region with a high level of exports, while the United States and the rest of Asia are considered as regions with high imports.

The results of this study show that production and consumption standards provide different emissions levels for each country from international transportation. In the case of China, both production standards and consumption standards showed the highest CO_2 emissions. China accounts for the greatest portion of international trade volumes. Since joining the World Trade Organization (WTO), China has increased its average annual export growth by more than 20% by 2012, becoming the world's largest exporter [39]. The United States has the second largest amount of emissions. The United States, which has relatively high import demand for international transportation, has more consumption-based emissions. In case of the EU, consumption-based emissions were estimated as being greater than production-based emissions. Other regions also differ in production- and consumption-based emissions, because the demand for international transportation varies from region to region. This means that the emissions responsibility for the reduction target can vary according to emissions standards. This results in the question of whether emissions responsibility is on the consumer or the producer, which is supported by the argument that many researchers should consider consumption standards in current production standards. There are clear problems with the existing approaches that have measured emissions worldwide using territory-based (production-based) criteria; this aspect should be fully discussed in the future, in view of the claim that emissions should also be measured on the basis of consumption.

4.2. Structural Decomposition Analysis Results

The SDA results are shown in Tables 5 and 6. EEFI, ESTR, Leontief, FD, and FDSTR represent the effect of change on emission efficiency, direct energy substitution effect, Leontief effects, final demand growth effect, and final demand structure change effect, respectively.

Table 5. Decomposition results of production-based emissions (mt).

Region	Periods	EEFI	ESTR	Leontief	FD	FDSTR
1 Oceania	2004–2007	−2.2859	−0.0272	−0.2619	3.3498	−0.2356
	2007–2011	−3.1451	0.0880	−0.1031	5.6040	−0.9455
2 Jpn	2004–2007	−0.1735	0.1620	−0.0940	0.3655	0.0457
	2007–2011	−1.0711	0.0291	−0.0346	0.4881	0.0934
3 Hkg	2004–2007	−0.0005	0.0000	−0.0001	0.0007	0.0003
	2007–2011	−0.0005	0.0002	−0.0001	0.0003	0.0000
4 Chn	2004–2007	−36.7169	2.6983	−0.6661	42.2985	3.7013
	2007–2011	−32.5167	−1.1720	−16.4126	45.1401	0.5397
5 Kor	2004–2007	4.6000	−4.6715	−0.0028	0.5309	−0.0181
	2007–2011	−2.4827	0.6108	−0.0824	0.8972	0.1382
6 Twn	2004–2007	−0.4907	−0.0458	0.0358	0.0664	0.0223
	2007–2011	−0.5189	−0.0868	−0.0105	0.3246	−0.0035
7 RAsia	2004–2007	−10.1637	−0.3329	−0.9523	10.0828	0.7145
	2007–2011	−9.3360	−0.3014	−2.1345	16.2162	−2.0455
8 USA	2004–2007	−3.9477	−0.4797	0.2306	6.2447	0.3478
	2007–2011	−2.2700	−1.2043	−0.8012	8.9201	0.8215
9 NAmerica	2004–2007	−2.7358	0.0793	−0.1525	10.5140	−0.3654
	2007–2011	−2.2783	−0.3724	−0.3168	3.2363	1.0211
10 LatinAmer	2004–2007	−6.0190	−1.7246	−0.5901	10.5991	2.0782
	2007–2011	−2.7550	−3.3019	−0.5850	6.1859	−0.8459
11 EU_28	2004–2007	−6.7153	1.0429	0.1614	3.0014	0.0095
	2007–2011	−4.0534	0.7220	−0.2361	2.1837	0.0918
12 ME	2004–2007	−4.8958	−0.1445	−0.2644	4.8240	−0.6406
	2007–2011	−3.4583	−0.7656	0.3949	6.8435	0.4267
13 Af	2004–2007	−3.4544	−0.2356	−0.6035	3.3791	0.3135
	2007–2011	−1.9239	−0.4048	−1.0735	2.5461	0.7710
14 RestofWorld	2004–2007	−8.7889	−0.5505	−2.6919	11.4688	−1.4967
	2007–2011	−8.5004	−0.1143	0.7348	7.9840	−0.3387

Table 6. Decomposition results of consumption-based emissions (mt).

Region	Periods	EEFI	ESTR	Leontief	FD	FDSTR
1 Oceania	2004–2007	−1.5513	0.047847	0.012399	0.766112	−0.06251
	2007–2011	−1.6647	0.083428	0.036569	1.541823	0.029795
2 Jpn	2004–2007	−0.3328	−0.05145	−0.04775	1.572684	2.203422
	2007–2011	−2.5738	0.06456	−0.08038	1.873794	−0.24711
3 Hkg	2004–2007	−0.0021	−0.00013	−0.00031	0.000345	0.000362
	2007–2011	−0.0015	0.000701	−0.00019	0.001096	9.81×10^{-5}
4 Chn	2004–2007	−27.391	3.132164	−2.77636	38.20948	−3.0402
	2007–2011	−28.3	0.08211	−16.0781	62.32876	−1.4885
5 Kor	2004–2007	5.63442	−3.57314	0.107275	2.055362	0.246521
	2007–2011	−6.2838	1.063381	−0.13576	2.693091	0.094727
6 Twn	2004–2007	−0.3562	−0.06087	0.021761	0.15281	0.029683
	2007–2011	−0.3878	−0.03812	−0.03461	0.252825	0.021777
7 RAsia	2004–2007	−9.5967	−0.46695	−1.0213	12.2335	0.842789
	2007–2011	−9.9522	0.836849	−2.10002	21.56441	−1.20804

Table 6. *Cont.*

Region	Periods	EEFI	ESTR	Leontief	FD	FDSTR
8 USA	2004–2007	−6.8445	−0.99009	−0.21461	11.98711	−0.50706
	2007–2011	−3.2481	−1.47546	−0.99722	5.378676	−0.09283
9 NAmerica	2004–2007	−2.1753	−0.13899	−0.08448	6.746482	−0.09585
	2007–2011	−1.6455	−0.56026	−0.27828	2.222925	0.756657
10 LatinAmer	2004–2007	−2.8628	−0.74261	−0.17203	3.594349	0.224472
	2007–2011	−1.3237	−1.50558	−0.46808	4.010768	−0.03148
11 EU_28	2004–2007	−8.3656	0.789585	0.114317	3.44293	0.264676
	2007–2011	−4.8904	0.56688	−0.27279	2.70455	0.189486
12 ME	2004–2007	−5.9124	0.137683	−0.37855	5.787716	−0.12602
	2007–2011	−4.1059	−0.36691	0.683202	7.090899	−0.03764
13 Af	2004–2007	−3.9734	0.288116	−0.60908	4.469598	0.248559
	2007–2011	−2.496	−0.56829	−1.3627	5.065184	−0.1159
14 RestofWorld	2004–2007	−7.1788	−0.41871	−2.52011	11.82117	−0.09322
	2007–2011	−7.0062	0.142143	0.533048	4.914443	−0.42874

First, we analyzed the factors of change in production-based emissions of major emitters. In case of China, during 2004–2007, CO_2 emissions increased by about 11 mt. The growth in total demand of international transport services played the largest role in the increase of CO_2 emissions, accounting for about 49%. The changes in emission efficiency followed behind, accounting for about 43% of the change in emissions. However, the two effects act in opposite directions and offset each other. The final demand structure, emission structure, and Leontief effects were 4%, 3%, and 1%, respectively, and had a relatively small impact. From 2007–2011, CO_2 emissions decreased by approximately 4 mt. The increased total volume of international transport services was still the largest factor behind the change of CO_2 emissions, accounting for about 47%. The second- and third- largest effects were emission efficiency and Leontief effect, which accounted for about 34% and 17%, respectively.

The largest change in emissions was due to international transportation services increasing emissions, but this was offset by the emission efficiency and the Leontief effect, resulting in a decrease in total emissions. In the case of the rest of Asia, which emits the second most CO_2, the emissions are high, but the total emission change is insignificant at 33 mt during the analysis period. Increases in international transport have increased emissions, but this has been offset by increased emissions efficiency and other effects that have reduced total emissions. Emissions of the United States increased slightly, from about 2 mt during 2004–2007 to about 5 mt over 2007–2011. The major factor for the increase in emissions is international transportation services, which accounts for 56% in 2004–2007 and 64% in 2007–2011.

The energy efficiency and emissions structure, which are the second- and third-largest contributors, decreased the total CO_2 emissions. In the case of North America, except the United States, CO_2 emissions increased by about 7 mt from 2004 to 2007, mainly due to the increase in international transportation demand, while emissions between 2007 and 2011 increased by only about 1 mt, due to the increase in emission efficiency. The emissions of the Middle East decreased slightly and then slightly increased during the analysis periods. The increase in final demand led to an increase in emissions, but the overall level remained similar due to increased emission efficiency. The EU and Africa are regions where emissions are decreasing gradually. A major factor in the reduction of emissions is increased emissions efficiency. The final demand for international transportation services has increased, but energy efficiency has increased more and so the total emissions have decreased. Looking at the impact of energy efficiency on emissions changes in the EU, this factor contributed approximately 61% of the changes from 2004–2007, and approximately 56% in 2007–2011. In addition, the emissions structure and final demand contributed 10% and 28% in 2004–2007, and 10% and 30% in 2007–2011, respectively.

Consumption-based emissions show that China also has the highest CO_2 emissions, and their emissions have increased very rapidly. In 2004, China's consumption-based emissions amounted to about 66 mt, rising to 74 mt in 2007 and 90 mt in 2011. The main reason for the increase in emissions, despite the increase in emission efficiency, is the increase in international transportation for imports during the analysis period. According to the World Bank, China's imports increased significantly from 2004 to 2011. The volume of international transport services importing to China seems to have increased significantly, resulting in an increase in emissions. In the rest of Asia, which had the second-largest amount of emissions, international transport demand has had the greatest impact, but total emissions increased by about 2 mt due to increased emission efficiency and changes in energy structure during 2004–2007, and then increased by 9 mt due to higher demand of international transport during 2007–2011. In the United States, emissions increased by about 3 mt due to the increase in international transportation in 2004–2007, but emissions then decreased slightly in 2007–2011, due to the relatively higher emissions efficiency and Leontief effects. In the Middle East region, emissions decreased mainly due to increased emission efficiency during 2004–2007; however, while the change in emissions was negligible, due to the increase in international transportation it increased by 3 mt in 2007–2011, 58% of which is due to the impact of international transportation growth. In other areas, the amount of emissions or the change in emissions is relatively small. Overall, international transportation demand growth and emission efficiency factors have had the greatest impact on emissions change. The EU is the only region where emissions are declining between major emitters. Increased emission efficiency has had a major impact on emission reduction. In the case of other major five emitters besides the EU, emissions have increased due to the increase in international transport demand, rather than the increase in emission efficiency.

5. Discussions and Conclusions

Globalization and the international division of labor have not only increased international trade, but have also significantly increased emissions of pollutants from international transport. Emissions from international transport are considerable, and are expected to increase substantially in the future. Despite this fact, it has been excluded from international discussion. Consideration of emissions from international transport is essential for achieving global emission reduction targets through accurate statistics. In this study, emissions from international transportation were examined by production and consumption standards. China has the highest CO_2 emissions in both production-based and consumption-based standards, because China is the world's largest exporter and accounts for the greatest share of world international trade volumes. The rest of Asia and the United States, which have the next highest emissions next to China, are also made up of regions with high trade volume. Their emissions have changed mainly due to the increase in international transport. The increase in international transportation services is a major cause of carbon emissions change. In China, the demand for international transportation services accounted for about 49% and 47% in the two studied periods, respectively, resulting in a significant increase in production-based emissions. In the United States and the rest of Asia, the increase in demand for international transportation services also had the greatest impact, and led to an increase in emissions. The decomposition analysis of consumption-based emissions showed similar results. On the other hand, in the EU, the amount of CO_2 emissions from international transportation has gradually decreased. Improved emission efficiency has had a major impact on emissions reduction. The EU appears to have reduced emissions intensity due to its strong eco-friendly policies, resulting in a decrease in total emissions. Global agreements can reduce global emissions through environmental pressures that reduce carbon dioxide emissions by industry.

However, emissions from production standards and consumption standards were different. China's production-based emissions are bigger than its consumption-based emissions. On the other hand, in the United States, consumption-based emissions are larger than production-based emissions.

Therefore, the United States is charged more responsibility for consumption-based emissions, which impose greater responsibilities on consumer standards, while China is the opposite. These results depend on the difference between import demand and export demand of international transportation services. As a result, the production and consumption standards provide different perspective on emissions.

Currently, production-based emissions are internationally accepted and used by the United Nations Framework Convention on Climate Change (UNFCCC). However, many scholars have argued that consumption-based emissions should also be considered, because production-based emissions estimates do not include international transport and are likely to overlook carbon leakage. Although consumption-based estimates mitigate these shortcomings, wide system boundaries and increased uncertainties in the data make it difficult to use as a unique indicator in climate policy [35]. There is still controversy about emissions measurement standards; this study has confirmed that the allocated emission amounts vary according to the standards used. As a result, changes in emissions from current production-based emissions to consumption-based emissions could change the emissions liability of intermediate-export-based and final-consumption-oriented countries. These results illustrate why carbon emissions should be distributed to both consumers and producers. Therefore, this perspective should be considered clearly in setting future emission standards.

The results of this paper do not show clear evidence that industrialized countries in the developed world are moving carbon intensive industries to developing countries. Clearly, emissions from developing countries are increasing, and emissions from industrialized countries are declining. Ensuring sustainable development and responding to climate change means that the role of developed countries in reducing emissions and the efforts of developing countries in the creation and diffusion of innovative technologies are both necessary. The benefits of assessing consumption-based emissions are also evident, in terms of carbon leakage and environmental considerations. The consumption base cannot be the only alternative to the production base, and using it also creates many issues. Problems caused by the assumptions of the linear proportions of the MRIO mentioned in previous studies, as well as the lack of international transportation data, are problems to be solved for more accurate measurement of emissions. Consumption-based emissions help differentiate promises, prioritize mitigation policies, and harmonize trade and climate policies. It is clear that this measure gives insight into climate policy. Therefore, discussions about which emissions standards are appropriate or how to harmonize the consumption and production standards for carbon emissions should be adequately discussed. The results of this study suggest that the CO_2 emissions from international transport should receive careful attention in the design of energy policies to limit CO_2 emissions globally.

Author Contributions: Conceptualization, J.K. and Y.Y.; Methodology, J.K., Y.Y., and M.Y.; Validation, J.K.; Formal Analysis, Y.Y. and M.Y.; Investigation, Y.Y. and M.Y.; Data Curation, Y.Y. and M.Y.; Writing-Original Draft Preparation, Y.Y.; Writing-Review & Editing, J.K. and M.Y.; Supervision, J.K.; Funding Acquisition, J.K.

Funding: This work was supported by the Human Resources Development program (No. 20174010201170) of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), grant-funded by the Korean government Ministry of Trade, Industry and Energy; and by the National Research Foundation of Korea by the Korean Government (grant number NRF-2015S1A3A2046684).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Regional classification.

No.	Region Code	Comprising	Region Description
1	Oceania	aus nzl xoc	Australia, New Zealand, Rest of Oceania
2	Ipn	jpn	Japan
3	Hkg	hkg	Hong Kong

Table A1. *Cont.*

No.	Region Code	Comprising	Region Description
4	Chn	chn	China
5	Kor	kor	Korea
6	Twn	twn	Taiwan
7	RAsia	mng xea brn khm idn lao mys phl sgp tha vnm xse bgd ind npl pak lka xsa	Mongolia, Rest of East Asia, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia, Bangladesh, India, Nepal, Pakistan, Sri Lanka, Rest of South Asia
8	USA	usa	United States of America
9	NAmerica	can mex xna	Canada, Mexico, Rest of North America
10	LatinAmer	arg bol bra chl col ecu pry per ury ven xsm cri gtm hnd nic pan slv xca dom jam pri tto xcb	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean
11	EU_28	aut bel cyp cze dnk est fin fra deu grc hun irl ita lva ltu lux mlt nld pol prt svk svn esp swe gbr bgr hrv rou	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Bulgaria, Croatia, Romania
12	ME	bhr irn isr jor kwt omn qat sau tur are xws	Bahrain, Iran, Israel, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of Western Asia, Egypt, Morocco, Tunisia, Rest of North Africa
13	Af	Egy mar tun xnf ben bfa cmr civ gha gin nga sen tgo xwf xcf xac eth ken mdg mwi mus moz rwa tza uga zmb zwe xec bwa nam zaf xsc	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Botswana, Namibia, South Africa, Rest of South African Customs
14	RestofWorld	Restofworld	Rest of the World

Appendix B

Table A2. Sectors classification.

No.	New Sector Code	Comprising	New Sector Description
1	GrainsCrops	pdr wht gro v_f osd c_b pfb ocr ctl oap rmk wol frs fsh	Paddy rice, wheat, cereal grains n.e.c. (not elsewhere classified), vegetable, fruit, nuts, oil seeds, sugar cane, sugar beet, plant-based fibers, crops n.e.c., cattle, sheep, goats, horses, animal products n.e.c., raw milk, wool, silk-worm cocoons, forestry, fishing
2	Coal	Coal	Coal
3	Oil	oil	Oil
4	Gas	gas	Gas
5	Min	omn	Minerals n.e.c.
6	MeatLstk	cmt omt vol mil pcr sgr ofd b_t	Meat, meat products n.e.c., vegetable oils and fats, dairy products, processed rice, sugar, food products n.e.c., beverages and tobacco products
7	TextWapp	Tex wap lea	Textiles, wearing apparel, leather products
8	WP	lum ppp	Wood products, paper products, publishing
9	CP	p_c	Petroleum, coal products

Table A2. *Cont.*

No.	New Sector Code	Comprising	New Sector Description
10	ChP	crp	Chemical, rubber, plastic prods
11	Nmm	nmm	Mineral products n.e.c.
12	FM	i_s nfm	Ferrous metals
13	MP	fmp	Metal products
14	Te	mvh otn	Motor vehicles and parts, transport equipment n.e.c.
15	ele	ele	Electronic equipment
16	ome	ome	Machinery and equipment n.e.c.
17	omf	omf	Manufactures n.e.c.
18	ely	ely	Electricity
19	Gdt	gdt	Gas manufacture, distribution
20	Wtr	wtr	Water
21	Util_Cons	cns	Utilities and Construction
22	Trd	trd	Trade
23	Trans	otp wtp atp	Transport n.e.c., sea transport, air transport
24	Cmn	cmn	Communication
25	Finnan	ofi isr	Financial services n.e.c.
26	Business	obs	Business service n.e.c.
27	PubAD	osg	PubAdmin/defence/health/educat
28	OthServices	ros dwe	Recreation and other services, dwellings

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