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A Research on Driving Factors of Carbon Emissions of Road Transportation Industry in Six Asia-Pacific Countries Based on the LMDI Decomposition Method

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Abstract: The transportation industry is the second largest industry of carbon emissions in the world, and the road transportation industry accounts for a large proportion of this in the global transportation industry. The carbon emissions of the road transportation industry in six Asia-Pacific countries (Australia, Canada, China, India, Russia, and the United States) accounts for more than 50% of this in the global transportation industry. Therefore, it is of great significance to study driving factors of carbon emissions of the road transportation industry in six Asia-Pacific countries for controlling global carbon emissions. In this paper, the Logarithmic Mean Divisia Index (LMDI) decomposition method is adopted to analyze driving factors on carbon emissions of the road transportation industry in six Asia-Pacific countries from 1990 to 2016. The results show that carbon emissions of the road transportation industry in these six Asia-Pacific countries was 2961.37 million tons in 2016, with an increase of 84.43% compared with those in 1990. The economic output effect and the population size effect have positive driving influences on carbon emissions of the road transportation industry, in which the economic output effect is still the most important driving factor. The energy intensity effect and the transportation intensity effect have different influences on driving carbon emissions of the road transportation industry for these six Asia-Pacific Countries. Furthermore, the carbon emissions coefficient effect has a relatively small influence. Hence, in order to effectively control carbon emissions of the road transportation industry in these six Asia-Pacific countries, it is necessary to control the impact of economic developments on the environment, to reduce energy intensity by promoting the conversion of road transportation to rail and water transportation, and to lower the carbon emissions coefficient by continuously improving vehicle emission standards and fuel quality.

Keywords: logarithmic mean Divisia index; road transportation industry; carbon emissions; driving factors

1. Introduction

Global warming has become one of the most important challenges for human beings, and the essential cause is excess emissions of greenhouse gases such as carbon dioxide, etc. According to the statistics of International Energy Agency Data (IEA Data), the transportation industry accounted for 23.96% of the 32.5804 billion tons of global carbon dioxide emissions in 2017, making it the second largest industry of carbon emissions. Among them, carbon emissions in sub-industries of road transportation accounted for the highest proportion of the transportation industry, with more than 70%. Furthermore, according to a rough calculation in this paper, the carbon emissions of the road transportation industry in six Asia-Pacific countries (Australia, Canada, China, India, Russia, and the United States) are about 50.81% of the global total volumes of that industry. Therefore, it is of great significance to study the driving factors of carbon emissions of the road transportation industry in these six Asia-Pacific countries for controlling global carbon emissions.

Currently, relevant researches on carbon emissions of the road transportation industry mainly involve two aspects: One is the relationship between carbon emissions and economic growth, and the other is the influence factors of carbon emissions. In terms of the relationship between carbon emissions and economic growth, Grossman et al. [1] firstly proposed an inverted U-shaped relationship between environmental quality and economic development based on Kuznets Curve (Kuznets [2]). Panayotou [3] called it the Environmental Kuznets Curve (EKC). Based on the EKC theory, Kwon [4] proposed, for the first time, that whether British road transportation was fit for the turning point of EKC should be verified. Abdallah et al. [5] verified, for the first time, that carbon emissions of road transportation in Tunisia conform to the law of EKC. With the same method, Kharbach et al. [6], Alshehry et al. [7], and Azlina et al. [8], respectively, verified the applicability of EKC in the road transportation industry in the United States, Saudi Arabia, and Malaysia. However, some scholars believe that some countries cannot verify that there is an EKC relationship between environment and carbon emission (Huang [9]).

In addition, some scholars have also verified the relationship between economy and environment through Decoupling Theory. The Organization for Economic Cooperation and Development (OECD) introduced "Decoupling Theory" and created the decoupling model. Lu [10] used this model to verify the decoupling relationship between the economic development and carbon emissions of the road transportation industry for Taiwan, Germany, Japan, and South Korea. The study revealed that Taiwan shows a decoupling relationship, while Korea, Germany, and Japan show a relative decoupling relationship. Tapio [11] optimized the basic decoupling model by introducing the elastic concept of economics and established the Tapio Decoupling Model to study the decoupling state of dynamic data. With this method, Sorrell et al. [12] analyzed the energy consumption of the road freight industry for Britain from 1989 to 2004 with the decoupling analysis method. The research results showed that the United Kingdom (UK) has been more successful than most European Union (EU) countries in decoupling the environmental influences of road freight transportation from GDP. Tapio [11] created a theoretical framework of decoupling to analyze carbon emissions of road transportation for the European Union from 1970 to 2001. The result indicated that the freight of the European Union transforms the relations from weak decoupling to expansive negative decoupling. In the 1990s, there existed a weak decoupling relation between freight transportation and carbon dioxide emissions in the UK, Sweden, and Finland, while a strong decoupling relation between road traffic volume and carbon dioxide emissions from the road transportation industry in Finland from 1990 to 2001. Kveiborg et al. [13] combined the Divisia Index Decomposition Method and Tapio Decoupling Model to analyze the carbon emissions of road freight from 1981 to 1997. The research results presented an obvious decoupling relationship in road freight from 1989 to 1997.

The decoupling model mainly calculates the decoupling index and the decoupling factor (OECD reference) to determine whether there is decoupling relationship between the environment and the economy; however, it cannot explain the specific reasons of decoupling. Therefore, some scholars have begun to study which factors have an influence on carbon emissions. At present, the research mainly focuses on using the factor decomposition method or the econometric model to analyze the influencing factors of carbon emissions. The factor decomposition method is mainly divided into the Laspeyres Index Decomposition method and the Divisia Index Decomposition method. (The Laspeyres Index Decomposition method follows the Laspeyres price and quantity indices in economics analysis.) Hankinson et al. [14], Reitler et al. [15], Howarth et al. [16], Howarth et al. [17], Park [18], Park et al. [19], and Lin [20] all used this method to analyze carbon emissions of different countries and regions. Due to the defect that the Factor-Reversal Test and the Time-Reversal Test cannot pass the tests in the Laspeyres Index method, Sobrino et al. [21] adopted the improved Laspeyres Index method to analyze driving factors for carbon emissions of the road transportation industry in Spain from 1990 to 2010. The conclusion showed that economic growth reveals a close relationship with the rise of carbon emissions, and improved energy efficiency has been a powerful contributor to the carbon emissions decrease.

Because relatively large residual errors in the calculated results in the Divisia Index Decomposition method exist, and it cannot solve the problem of zero value, Ang et al. [22] proposed the Logarithmic Mean Divisia Index (LMDI) in 1998. It effectively solves the above problems and acquires a wide range of applications. M'raihi et al. [23] adopted this method to study the influencing factors of carbon emissions of the road transportation industry in Tunisia. The research results showed that economic growth is the main reason for the increase of carbon dioxide emissions. Effects of fossil fuel share, fossil fuel intensity, and road freight transport intensity are all found as secondary factors responsible for CO_2 emission changes, while Timilsina et al. [24] considered that the economic activity effect and the transportation energy intensity effect are found to be the main driver of CO_2 emissions of road transportation in Latin American and Caribbean countries. Liu et al. [25], Howarthetal et al. [16], Paul et al. [26], and Lise [27] all used this method to analyze the relationship between energy consumption and carbon emissions.

Econometric models can effectively analyze time series data. Wei [28] used the impulse response function and the factor decomposition method to study the carbon emissions of China's road transportation industry. The research results showed that traffic structure and carbon emissions had long-term influences and that dynamic interactive mechanisms exited in China from 1989 to 2009. Wang et al. [29] used a combined research model, including co-integration analysis, the error correction model, and the dynamic model, to study the influences of different factors on energy consumptions in China and OECD countries. However, the paper only showed the strong and weak relationship of each factor—it did not quantify their influence degrees. Liimatainen et al. [30] firstly proposed the "road freight–economy" relationship analysis framework (McKinnon et al. [31]) for McKinnon's improvement, and introduced three indexes of CO_2 intensity, transport intensity, and energy efficiency. He used a joint analysis method for comparison to analyze carbon dioxide emissions and energy efficiencies of the road transportation industry for the four countries of Denmark, Finland, Norway, and Sweden in northern Europe in 2010. It indicated that transportation intensity and energy efficiency have significant influences on carbon dioxide emissions. Puliafito et al. [32] calculated the carbon emissions data of Argentina's road transportation industry from 1960 to 2010 and predicted the data from 2011 to 2050, and Monte Carlo sensitivity analysis and scenario analysis methods were applied to analyze the relations between energy demand and greenhouse gas emissions. Melo [33] applied both the spatial and non-spatial panel data models and introduced ten influence factors, such as urbanization, vehicle ownership, and income levels, etc., to analyze the causal relationship between demand-led, as well as supply-led, factors and carbon emissions of the road transportation industry. The multi-factor and multi-angle analysis strategy provided in the paper can provide a basis for future researches on causality and influence factors. Hasan et al. [34] used a multiple regression model to determine the main driving factors of transportation emissions of passenger vehicles in New Zealand. The results showed that there is a significant causal relationship between fuel economy and transportation emissions. The present study can provide reference values for future studies in different effect factors, and might offer further policy implications for other countries. Sundo [35], adopting a new mathematical original-destination (O-D) approach of estimating CO_2 emissions, made a comparison among five different low-carbon scenarios. The results showed that increasing the proportion of clean energy can effectively reduce the carbon emissions of the road transportation industry.

Seen from the above references, scholars at home and abroad have conducted in-depth researches on the carbon emissions of the road transportation industry, but several problems also exist, as follows: (1) The expansion of Kaya identity is a little simpler when the factor decomposition method is used to analyze carbon emissions of transportation industry; and (2) currently, only a few scholars conduct comparative studies among countries, while other scholars take only one country as the research object, failing to fully explain the differences of carbon emissions among countries. This paper takes six Asia-Pacific countries as the research object, and expands Kaya identity by introducing transportation turnover and other indexes, so as to analyze the influence of more factors on the carbon emissions of the road transportation industry. The LMDI decomposition method is used to emphatically discuss the driving factors of carbon emissions of road transportation, and comparative studies among the six countries are conducted to analyze the influence mode and degree of various factors on carbon emissions of the road transportation industry in these six countries.

2. Research Method

2.1. Expansion of Kaya Identity

Kaya identity, firstly proposed by Japanese professor Yoichi Kaya at the seminar of Intergovernmental Panel on Climate Change (IPCC) in 1989 [36], establishes a relationship between carbon dioxide emissions and economic, policy, as well as population factors, etc. It can decompose driving factors for carbon dioxide emissions and quantify the contribution rate of each influencing factor accurately. Its expression is as follow:

$$C = \frac{GDP}{POP} \times \frac{PE}{GDP} \times \frac{C}{PE} \times POP \tag{1}$$

In Formula (1), C, POP, GDP, and PE respectively represent the volume of carbon dioxide emissions, the whole population of a country, gross domestic product, and total energy consumption.

Kaya identity has been widely used in the fields of energy, environment, and economy. However, due to the limited numbers of examined variables, the results obtained are basically confined to the quantitative relationships between carbon dioxide emissions and energy, economy, and population at the macro level. In recent years, when studying influencing factors for carbon emissions of road transportation, most scholars have mainly selected population size, GDP per capita, and the carbon emissions coefficient of energy [37–39]. However, since carbon emissions are not only connected to these factors, but also relatively closely related to factors of transportation intensity and energy intensity, etc., the index of road transportation turnover is added in this paper, and the Kaya identity is extended. The expression of the expanded Kaya identity is as follows:

$$C = \frac{GDP}{POP} \times \frac{TRS}{GDP} \times \frac{PE}{TRS} \times \frac{C}{PE} \times POP \tag{2}$$

In Formula (2), GDP and POP have the same meaning as Formula (1); C represents total carbon emissions of a country's road transportation industry; TRS says road transportation turnover of a country; and PE indicates energy consumptions of a country's road transportation industry.

Let:

$$G = \frac{GDP}{POP};\quad R = \frac{TRS}{GDP};\quad P = \frac{PE}{TRS};\quad S = \frac{C}{PE};\quad O = POP \tag{3}$$

Formula (2) can be simplified into Formula (4) by applying Formula (3):

$$C = G \times R \times P \times S \times O \tag{4}$$

In Formula (4), G, R, P, S, and O respectively represent economic output, transportation intensity, energy intensity, and the carbon emissions coefficient of energy, as well as population size.

2.2. The LMDI Decomposition Method Based on Extended Kaya Identity

The factor decomposition method is a further extension of Kaya identity, mainly including the Laspeyres Index decomposition method, the Logarithmic Mean Divisia Index (LMDI) decomposition method, and the Fisher's Ideal Index method, etc. Among them, the LMDI decomposition method, proposed by Ang. B.W. etc. in 1998, solved the problems of inherent salvage value and zero value for the index decomposition method. It witnesses an advantage of complete decomposition and the results' uniqueness [22,40]. Therefore, the LMDI decomposition method has become a mainstream research tool in the field of energy and environment.

The LMDI decomposition method includes the two specific methods of additive decomposition and multiplication decomposition [41]. Because decomposition results of the two methods can be converted to each other, and their converted results are consistent, this paper adopts the additive decomposition method to decompose the model shown in Formula (4). The specific formula is shown in Formula (5).

$$\Delta C = DG + DR + DP + DS + DO \tag{5}$$

In Formula (5), DG represents economic output effect, DR represents transportation intensity effect, DP represents energy intensity effect [42], DS represents carbon emissions coefficient effect of energy, and DO represents population size effect. Hence, the formulas for calculating the effects of various factors influencing carbon emissions are shown in Formulas (6)–(10), and the detailed calculation process is included in the Appendix A.

$$DG = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln\left(\frac{G^t}{G^0}\right) \tag{6}$$

$$DR = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln\left(\frac{T^t}{T^0}\right) \tag{7}$$

$$DP = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln\left(\frac{P^t}{P^0}\right) \tag{8}$$

$$DS = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln\left(\frac{S^t}{S^0}\right). \tag{9}$$

$$DO = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln\left(\frac{O^t}{O^0}\right) \tag{10}$$

Here, among Formulas (6)–(10), C^0 indicates the baseline year value of carbon emissions for one country's road transportation industry; C^t represents carbon emissions of a country's road transportation industry in year T; G^t, R^t, P^t, S^t, and O^t respectively show the economic output, transport intensity, energy intensity, the carbon emissions coefficient of energy, and population size in the Tth year of a country's road transportation industry; and G^0, R^0, P^0, S^0, and O^0 respectively show a baseline year's economic output, transport intensity, energy intensity, energy coefficient of carbon emissions, and population size of a country's road transportation industry.

3. Description of Variables and Data

This paper selects China and India in Asia, and the United States, Canada, Australia, and Russia in the Pacific Rim, with a total of six countries. The selected countries are characterized by the following commonalities: That all of the six countries respectively have a large territory area, and their carbon emissions from the road transportation industry account for a large proportion of that from the transportation industry. In addition, all of them, being members of the World Trade Organization (WTO), have a sound multilateral trading system and all of their total economic aggregates rank among the top in the world. Therefore, meaningful research conclusions can be obtained by comparing and analyzing the factors influencing carbon emissions of the road transportation industry in these six countries. The research interval of this paper is from 1990 to 2016, and the data in this paper come from the International Energy Agency database (IEA database), the United Nations database (UN database), and the World Bank database.

3.1. Decomposed Variables and Their Database Sources

Carbon emissions refer to the general term of greenhouse gases, expressed by carbon dioxide equivalent (CO_2eq). It mainly includes carbon dioxide, methane, nitrous oxide, and other carbon oxides, among which carbon dioxide emissions account for more than 60% of greenhouse gas emissions. Due to a lack of comprehensive statistics of global carbon emissions at present, most scholars adopt methods provided by IPCC national guidelines for inventory calculations of greenhouse gas [42], and use energy consumption data to calculate carbon emissions. Therefore, the specific expression formula of carbon emissions adopted in this paper is as follows:

$$C = \sum_i^n CO_{2i} = \sum_i^n E_i \times \delta_i = \sum_i^n E_i \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12} \tag{11}$$

where CE stands for carbon dioxide emissions from road transportation industry; i is the type of fossil fuel (the IEA database classifies fuels consumed by the road transportation industry into five categories: Coal, petroleum products, biomass energy, natural gas, and electricity); E_i refers to energy consumption of fossil fuel I; δ_i is the carbon dioxide emission coefficient of carbon energy i; NCV_i is the average low calorific value of energy i; CEF_i is the carbon emissions coefficient of energy i, namely, the carbon content per unit of heat; COF_i is the carbon oxidation factor, that is, the carbon oxidation rate during energy combustion; and 44 and 12 are the molecular weights of carbon dioxide and carbon [43].

According to the glosses of International Energy Agency database [44], the unit for all energy consumption is oil equivalent, and the carbon emissions coefficients of various energies are shown in Table 1.

Table 1. Carbon emissions coefficients of transportation and energy.

Types of Energy	Conversion Factor (KJ/toe)	Carbon Oxidation Rate	CO_2 Emission Factor (kgCO_2/GJ)
Coal	41,868	1	94.6
Oil products	41,868	1	72.35
Biomass energy	41,868	1	75.18
Natural gas	41,868	1	56.1
Electric power	-	-	-

Note: Data source: Intergovernmental Panel on Climate Change (IPCC) 2006 edition.

Since electricity is a secondary energy, and carbon emissions from electricity of the road transportation industry in the six Asia-Pacific countries in 2016 only account for 1.50% of total carbon emissions of all energy consumptions, the method to calculate carbon emissions of electricity in this paper is to convert the energy consumption of electricity into equivalent standard coal, and then use the carbon emissions of standard coal to represent the carbon emissions of electricity.

3.2. Decomposition Variables and Their Data Sources

The driving factors of the decomposition model for carbon emissions based on LMDI mainly include economic output, transportation intensity, energy intensity, the carbon emissions coefficient, and population size. The data of the six countries' GDP and population are derived from the UN database, in which the GDP of the six countries is calculated by constant 2010 prices in US Dollars. Road transportation turnover comes from the World Bank database. Energy consumptions of road transportation based on the energy consumptions of the IEA database are converted to standard coal by the method of "oil equivalent–calorific value–standard coal". The detailed forms are shown in Tables 2 and 3.

Table 2. The element's description and data sources.

Elements	Description	Data Resource
GDP	Gross Domestic Production at constant 2010 prices in US Dollars	UN database
POP	Population	UN database
TRS	Total road turnover	World Bank database
PE	Total energy consumption of road transportation	IEA database
C	Total CO_2 emissions of road transportation	Estimate by Formula (11)

Table 3. The driving factors of the decomposition model.

Driving Factors	Description	Symbols
G	Economic output	G = GDP/POP
R	Transportation intensity	R = TRS/GDP
P	Energy intensity	P = PE/TRS
S	Carbon emissions coefficient	S = C/PE
O	Population size	O = POP

3.2.1. Economic Output

According to Figure 1, China's per capita GDP in 2016 increased by 857.20% compared with that in 1990, ranking first among the six countries. The per capita GDP of Russia in 2016 increased by 19.00% compared with 1990, being last among the six countries. In 2016, China's per capita GDP reached $6,770 per person, Russia's $11,500 per person, while the per capita GDP of Australia, Canada, and the United States exceeded $50,000 per person.

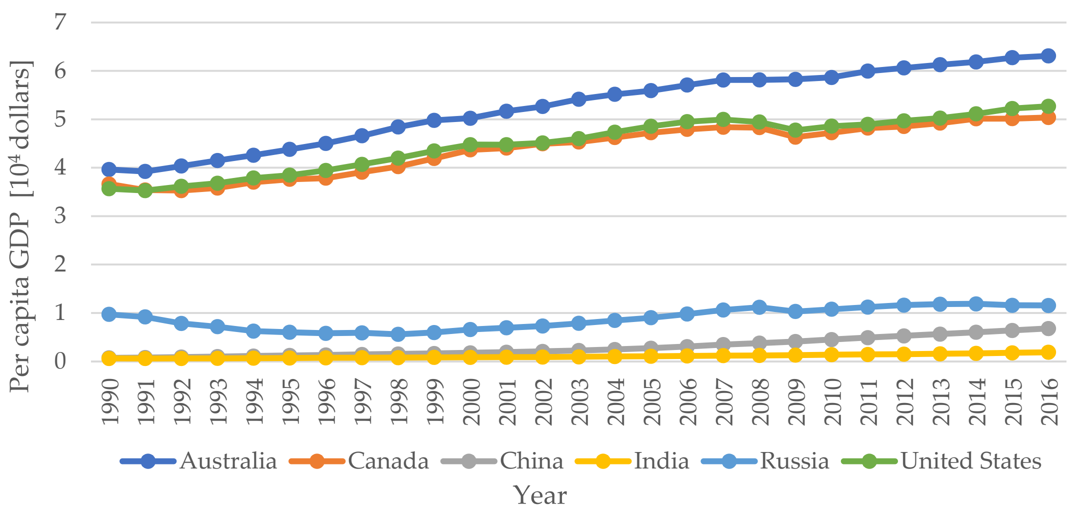

Figure 1. Per capita GDP of six Asia-Pacific countries from 1990 to 2016. Note: Data source: United Nations (UN) database.

3.2.2. Transportation Intensity

The transportation intensity of the six countries is shown in Figure 2. Indian transportation intensity of the road transportation industry is highest in 2016, reaching 1620.96 million tonne-kilometer/$billions, secondary in China at 653.77 million tonne-kilometer/$billions, and lowest in Canada at 121.96 million tonne-kilometer/$billions. In addition, India's road transportation industry presents the largest increase in transport intensity, with 269.04% growth in 2016 compared with 1990, ranked first among all countries, followed by Canada with an increase of 28.94%. In the study range, the transportation intensity of the United States and Russia show a decreasing trend. The transportation intensity of the United States decreased by 23.01% in 2016 compared with 1990, while that of Russia decreased by 35.04%. The reason for the high transportation intensity of India lies in its relatively high proportion of manufacturing and agriculture, and relatively high proportion of road transportation in the five transportation modes. China witnessed a high transportation intensity, which is also due to its relatively high proportion of manufacturing industry in its national economic industry.

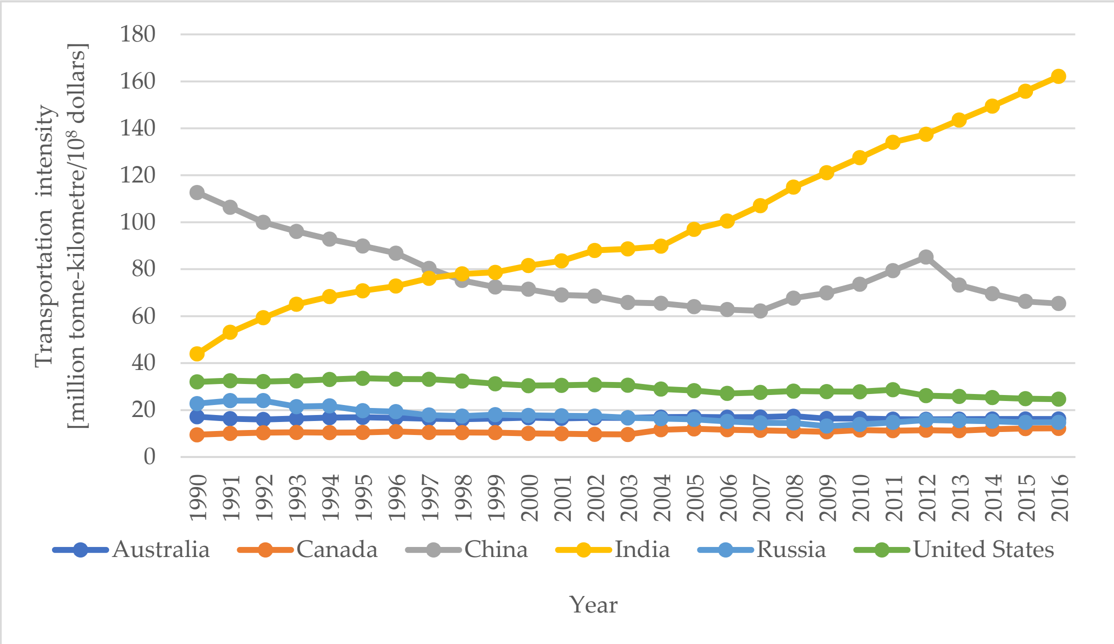

Figure 2. Transportation intensities of six Asia-Pacific countries from 1990 to 2016. Note: Data source: Organization for Economic Cooperation and Development (OECD) Database.

3.2.3. Energy Intensity

The changes of energy intensity for the road transportation industry in the six Asia-Pacific countries are shown in Figure 3. While energy intensities of the road transportation industry in Australia, Canada, United States, and India show decreasing trends within the research range, energy intensities of China and Russia increase by 45.26% and 20.78% respectively. In 2016, Canada's road transportation industry showed the highest energy intensity, reaching 3.09 tons per million tonne-kilometers; Russia's was second at 2.88 tons per million tonne-kilometers; and the United States' third, with 1.81 tons per million tonne-kilometers. The reason for India's low energy intensity is that motorcycles account for nearly 80% of all motor vehicles in India, while trucks and lorries account for only 5.3%. The energy consumption of motorcycles is far less than that of vehicles with four wheels or above. The reason for China's low energy intensity is that the statistics of China's road transport industry cover operating vehicles, excluding private cars, while the statistics of the other five countries cover private cars.

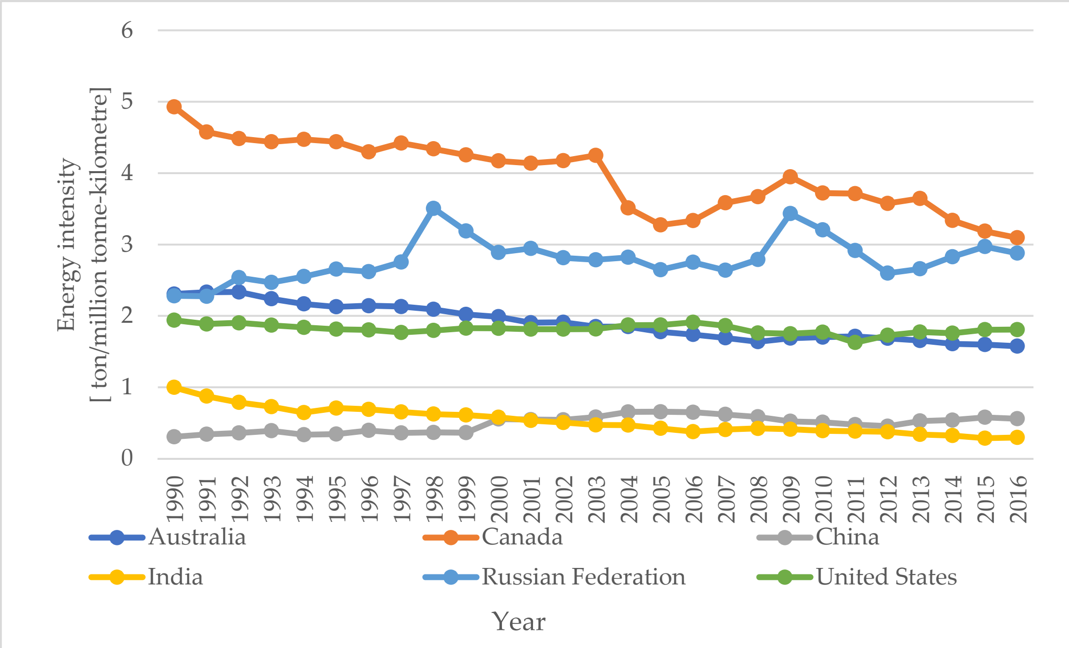

Figure 3. Energy intensities of the six Asia-Pacific countries from 1990 to 2016. Note: Data source: International Energy Agency (IEA) database.

3.2.4. Population Size

The population sizes of the six Asia-Pacific countries are shown in Figure 4. In the study range, the population sizes of the countries, except Russia, have increased to some extent. Among them, India's population in 2016 increased by 52.18% compared with 1990, ranking first among the six countries, while Russia's decreased by 2.44% year-on-year, ranking last of countries. In 2016, China and India, respectively, had a population of 1.403 billion and 1.324 billion, accounting for 43.13% and 40.69% of the total population of the six Asia-Pacific countries.

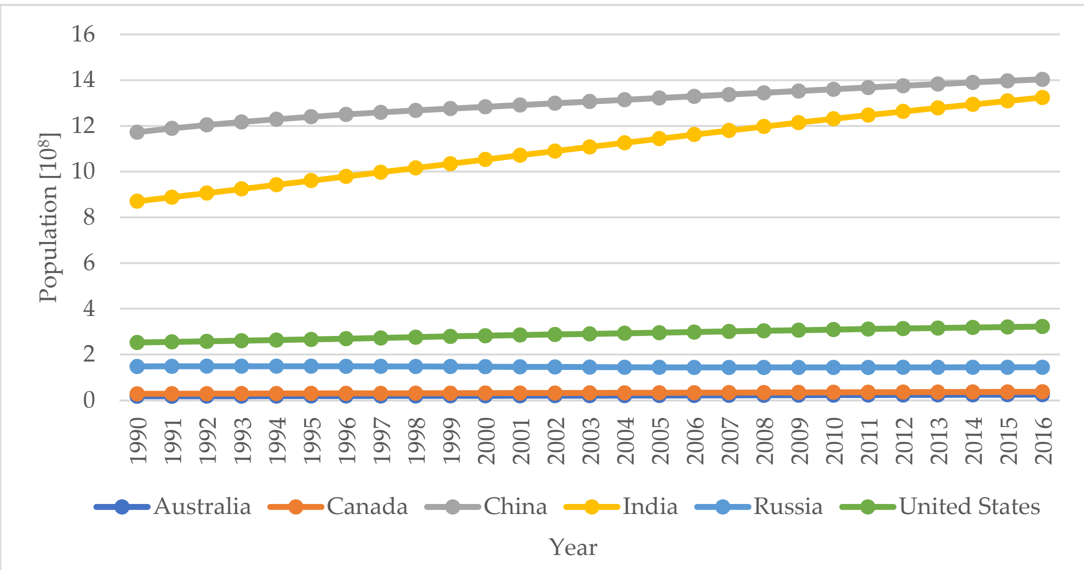

Figure 4. Population sizes of the six Asia-Pacific countries from 1990 to 2016. Note: Data source: United Nations (UN) database.

3.2.5. Carbon Emissions Coefficient

The carbon emissions coefficients of the six Asia-Pacific countries are shown in Figure 5. Within the research range, the carbon emissions coefficients of the six Asia-Pacific countries show downward trends, but the decline is relatively small.

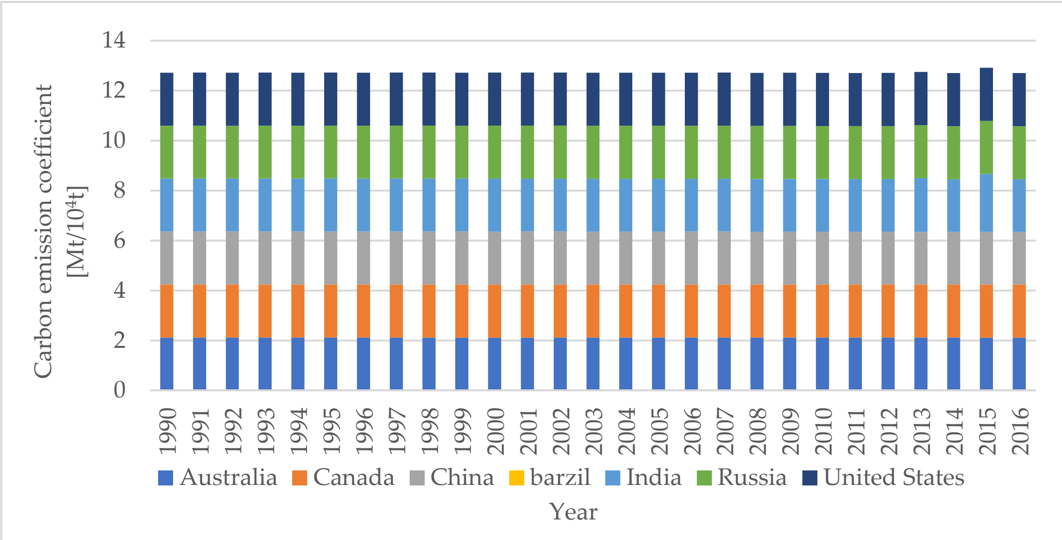

Figure 5. Carbon emissions coefficients of the six Asia-Pacific countries from 1990 to 2016. Note: Data source: International Energy Agency (IEA) database.

4. Results and Discussions

4.1. Analysis on Total Carbon Emissions

The results of the calculation for carbon emissions of the road transportation industry in the six Asia-Pacific countries from 1990 to 2016 are shown in Figure 6 and Table 4. The total carbon emissions from the road transportation industry of the six countries increased from 1605.73 million tons in 1990 to 2961.37 million tons in 2016. Among them, in 2016, the combined carbon emissions from the road transportation industry of the United States and China accounted for 53.73% of the total volume of the six countries. On the whole, carbon emissions of the road transportation industry in the six countries in the study range increased rapidly, among which the average annual growth rate of China's carbon emissions is 9.65%, far higher than those of other countries; India ranks second with 6.36%, and Russia last with a rate of −0.17%.

On the other hand, in the United States and Canada, appeared turning points appeared in carbon emissions in 2007 and 2011, respectively. In 2016, the per capita carbon emissions of China and the United States far exceeded those of the other countries, reaching 4.04 tons and 4.99 tons per capita, respectively.

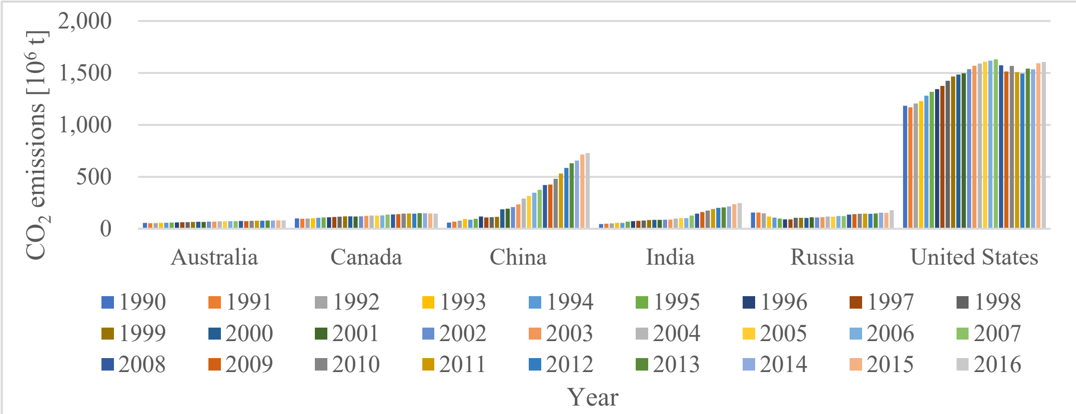

Figure 6. Carbon emissions of road transportation in the six Asia-Pacific countries from 1990 to 2016.

Table 4. Carbon emissions from road transportation in the six Asia-Pacific countries.

Country	Average Annual Growth Rate (%)	Carbon Emissions in 1990 (million tons)	Carbon Emissions in 2016 (million tons)	1990–2016 Increasing Multiples of Carbon Emissions	Turning Points' Year for Carbon Emissions	Per capita Carbon Emissions in 2016 (ton/person)
Australia	1.46%	56.68	82.29	0.45	-	3.41
Canada	1.49%	100.36	146.60	0.46	2011	4.04
China	10.67%	60.58	728.49	11.03	-	0.52
India	6.76%	46.95	247.94	4.28	-	0.19
Russia	0.78%	156.77	177.94	0.14	-	1.24
United states	1.20%	1184.39	1606.24	0.36	2007	4.99
Total	22.36%	1605.73	2989.51	16.71	-	14.38

Note: Data source: The International Energy Agency database.

4.2. Analysis on Main Driving Effect

While calculated with Formulas (5)–(10), the years from 1990 to 2016 are divided into nine time periods at intervals of three years. The effect value and contribution rate of every factor driving carbon emissions of road transportation industry are calculated separately in each time period. This paper uses the LMDI decomposition method to decompose carbon emissions of the road transportation industry in the six Asia-Pacific countries. They are mainly decomposed into economic output effect, transportation intensity effect, energy intensity effect, energy carbon emissions coefficient effect, and population size effect, and the calculated effect value and contribution rate of each factor. The contribution rate of each influence factor is the ratio of effect value of the influencing factor to the total effect value of carbon emissions, e.g., $B_{DG} = DG/\Delta C$, whose results are shown in Tables 5 and 6. Seen from the decomposition results, the economic output effect presents the largest contribution rate, the population size effect is the second, and the carbon emissions coefficient the smallest. Therefore, the economic output and population size effects are the main driving factors for the growth of carbon emissions from the road transportation industry in the six Asia-Pacific countries.

Table 5. LMDI decomposition results of carbon emissions from road transportation in the six Asia-Pacific countries (unit: million tons).

Australia	DG	DR	DP	DS	DO	ΔC	China	DG	DR	DP	DS	DO	ΔC
1990–1992	1.01	−4.00	0.72	−0.01	1.45	−0.82	1990–1992	13.51	−7.16	9.97	0.02	1.84	18.18
1993–1995	3.14	1.83	−3.01	0.00	1.28	3.36	1993–1995	19.84	−7.37	−11.22	0.01	1.77	3.47
1996–1998	4.58	−2.27	−1.48	−0.01	1.35	2.24	1996–1998	17.26	−7.41	−17.50	−0.01	1.60	−5.29
1999–2001	2.45	0.41	−3.92	−0.03	1.40	0.34	1999–2001	22.58	−8.45	62.81	−0.01	1.83	79.73
2002–2004	3.32	1.14	−2.29	0.00	1.71	3.70	2002–2004	44.58	−12.40	46.61	−0.59	2.91	82.39
2005–2007	2.84	−0.27	−3.61	0.01	2.53	0.54	2005–2007	83.42	3.20	−33.09	0.33	3.95	59.15
2008–2010	0.66	−4.49	2.87	−0.01	2.71	0.65	2008–2010	81.02	37.72	−63.60	0.03	5.12	61.41
2011–2013	1.74	0.00	−2.72	0.00	2.34	0.71	2011–2013	80.71	−46.93	58.87	−1.18	6.46	98.94
2014–2016	1.62	0.02	−1.74	−0.02	2.22	1.60	2014–2016	84.51	−42.65	23.44	0.34	6.63	74.19
1990–2016	31.96	−4.03	−26.15	−0.03	23.88	25.62	1990–2016	606.64	−146.15	161.82	−2.71	48.31	667.91
Canada	**DG**	**DR**	**DP**	**DS**	**DO**	**ΔC**	**India**	**DG**	**DR**	**DP**	**DS**	**DO**	**ΔC**
1990–1992	−3.72	9.17	−9.42	0.00	2.46	−1.51	1990–1992	0.83	15.02	−11.80	0.00	2.02	6.06
1993–1995	5.16	−0.15	0.02	0.00	2.24	7.50	1993–1995	6.69	5.30	−1.68	0.00	2.42	12.79
1996–1998	6.97	−4.14	1.11	0.01	2.11	6.50	1996–1998	4.98	5.31	−7.70	0.00	2.86	5.61
1999–2001	5.91	−5.46	−3.28	0.07	2.22	−0.21	1999–2001	4.69	5.16	−11.32	−0.12	2.98	1.69
2002–2004	3.53	22.70	−21.42	−0.01	2.47	7.33	2002–2004	11.86	1.89	−7.15	−0.10	3.06	10.06
2005–2007	3.16	−7.48	11.97	0.05	2.97	10.26	2005–2007	13.86	11.39	−4.63	0.04	3.51	24.98
2008–2010	−3.17	5.26	1.96	0.04	3.23	6.74	2008–2010	20.77	16.61	−12.92	−0.20	4.47	30.23
2011–2013	3.16	−0.19	−2.69	0.02	3.06	3.01	2011–2013	17.88	13.51	−24.44	4.26	4.92	18.45
2014–2016	0.73	4.57	−10.73	−0.02	2.82	−2.62	2014–2016	28.67	18.78	−20.26	0.02	5.36	35.49
1990–2016	38.91	31.02	−56.80	0.13	32.99	46.25	1990–2016	140.19	157.71	−146.96	−0.66	50.72	200.99
Russia	**DG**	**DR**	**DP**	**DS**	**DO**	**ΔC**	**United States**	**DG**	**DR**	**DP**	**DS**	**DO**	**ΔC**
1990–1992	−32.59	8.10	16.17	−0.04	0.78	−7.57	1990–1992	17.00	4.78	−23.65	0.00	23.08	21.20
1993–1995	−19.14	−8.89	7.89	0.15	−0.10	−19.70	1993–1995	56.71	42.59	−38.76	0.34	27.32	85.83
1996–1998	−3.60	−10.16	28.73	−0.05	−0.46	15.30	1996–1998	86.64	−36.00	−6.14	0.10	34.28	72.74
1999–2001	16.55	−2.88	−8.61	0.14	−0.82	5.39	1999–2001	43.15	−31.96	−12.38	−0.01	31.49	30.59
2002–2004	16.90	−7.20	0.30	0.00	−0.91	9.74	2002–2004	75.27	−97.33	49.48	0.33	27.13	63.41
2005–2007	19.63	−11.95	−0.33	−0.07	−0.39	6.87	2005–2007	45.98	−46.45	−8.04	0.70	29.72	31.21
2008–2010	−5.34	−6.18	19.62	0.00	0.07	7.45	2008–2010	−27.64	−15.78	10.31	0.36	27.04	6.16
2011–2013	7.55	7.46	−13.53	0.07	0.34	0.70	2011–2013	39.93	−106.80	78.42	1.00	21.83	49.78
2014–2016	−4.78	−4.29	2.71	−0.07	0.22	−6.22	2014–2016	47.14	−44.00	44.78	0.31	21.90	84.54
1990–2016	26.67	−66.12	35.69	0.59	−3.78	-6.96	1990–2016	540.90	−362.01	−97.61	3.30	337.27	421.84

Table 6. Contribution rates of carbon emission drivers for road transportation in the six Asia-Pacific countries (unit: %).

Australia	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}	**China**	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}
1990–1992	−122.52	485.53	−87.95	0.75	−175.82	100	1990–1992	74.33	−39.37	54.83	0.09	10.12	100
1993–1995	93.56	54.60	−89.70	0.02	38.02	100	1993–1995	571.10	−212.22	−323.04	0.36	51.00	100
1996–1998	204.57	−101.31	−66.10	−0.55	60.17	100	1996–1998	−326.31	140.06	330.70	0.24	−30.17	100
1999–2001	729.70	122.35	−1169.14	−10.11	416.27	100	1999–2001	28.32	−10.59	78.77	−0.01	2.29	100
2002–2004	89.81	30.75	−61.91	−0.09	46.24	100	2002–2004	54.11	−15.06	56.57	−0.71	3.53	100
2005–2007	525.30	−50.31	−667.91	2.03	467.42	100	2005–2007	141.03	5.41	−55.95	0.56	6.67	100
2008–2010	101.61	−687.50	439.48	−0.87	415.45	100	2008–2010	131.92	61.41	−103.56	0.04	8.34	100
2011–2013	245.41	0.66	−383.39	−0.70	329.49	100	2011–2013	81.57	−47.43	59.50	−1.19	6.52	100
2014–2016	101.12	1.09	−108.66	−1.48	139.00	100	2014–2016	113.91	−57.49	31.60	0.46	8.94	100
1990–2016	124.76	−15.74	−102.10	−0.14	93.22	100	1990–2016	90.83	−21.88	24.23	−0.41	7.23	100
Canada	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}	**India**	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}
1990–1992	245.81	−605.44	622.05	−0.13	−162.29	100	1990–1992	13.67	247.88	−194.86	−0.01	33.30	100
1993–1995	68.76	−1.94	0.28	−0.02	29.89	100	1993–1995	52.27	41.46	−13.16	0.00	18.89	100
1996–1998	107.34	−63.70	17.12	0.15	32.51	100	1996–1998	88.88	94.73	−137.35	0.01	51.01	100
1999–2001	−2823.09	2606.35	1565.11	−32.56	−1058.92	100	1999–2001	276.95	304.54	−667.93	−7.23	175.75	100
2002–2004	48.15	309.83	−292.37	−0.08	33.70	100	2002–2004	117.91	18.82	−71.09	−1.02	30.37	100
2005–2007	30.83	−72.95	116.69	0.47	28.91	100	2005–2007	55.48	45.58	−18.53	0.15	14.07	100
2008–2010	−47.01	78.05	29.02	0.54	47.92	100	2008–2010	68.70	54.94	−42.72	−0.67	14.80	100
2011–2013	104.77	−6.21	−89.25	0.54	101.48	100	2011–2013	96.92	73.22	−132.46	23.06	26.65	100
2014–2016	−27.90	−174.25	409.06	0.67	−107.58	100	2014–2016	80.77	52.91	−57.10	0.06	15.09	100
1990–2016	84.14	67.07	−122.83	0.29	71.34	100	1990–2016	69.75	78.47	−73.12	−0.33	25.23	100
Russia	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}	**United States**	B_{DG}	B_{DR}	B_{DP}	B_{DS}	B_{DO}	B_{DC}
1990–1992	430.34	−106.93	−213.59	0.48	−10.29	100	1990–1992	80.15	22.55	−111.54	0.00	108.84	100
1993–1995	97.15	45.15	−40.07	−0.75	0.53	100	1993–1995	66.07	49.62	−45.16	0.40	31.83	100
1996–1998	−23.54	−66.43	187.78	−0.34	−3.02	100	1996–1998	119.11	−49.49	−8.44	0.14	47.12	100
1999–2001	306.86	−53.49	−159.74	2.58	−15.15	100	1999–2001	141.08	−104.47	−40.49	−0.03	102.94	100
2002–2004	173.56	−73.98	3.09	0.01	−9.35	100	2002–2004	118.70	−153.49	78.02	0.52	42.79	100
2005–2007	285.82	−173.92	−4.79	−0.96	−5.70	100	2005–2007	147.30	−148.80	−25.77	2.25	95.22	100
2008–2010	−71.66	−82.98	263.47	0.04	0.93	100	2008–2010	−449.03	−256.36	167.53	5.89	439.32	100
2011–2013	1085.39	1072.53	−1945.79	9.77	49.18	100	2011–2013	80.20	−214.52	157.53	2.02	43.85	100
2014–2016	76.92	68.91	−43.51	1.15	−3.47	100	2014–2016	55.77	−52.05	52.97	0.37	25.91	100
1990–2016	−383.12	950.05	−512.81	−8.49	54.38	100	1990–2016	128.22	−85.81	−23.14	0.78	79.95	100

4.2.1. Economic Output Effect

As can be seen from Table 5, most of the economic output effect values of the six countries in the research interval are positive, and only a few years witness small negative values of absolute values. This indicates that the economic output effect plays a positive driving role in the carbon emissions of the road transportation industry.

Seen from Figure 7, the values of the economic output effect for the United States, Canada, Russia, and Australia present an overall inverted "U" pattern, which conforms to the development law of the environmental Kuznets curve. China and India are both developing countries; their national economy and industrialization are in a stage of rapid development, and they are still at the left end of the environmental Kuznets curve, having no turning points yet. Therefore, the influence of economic output on carbon emissions of the road transportation industry continues to increase.

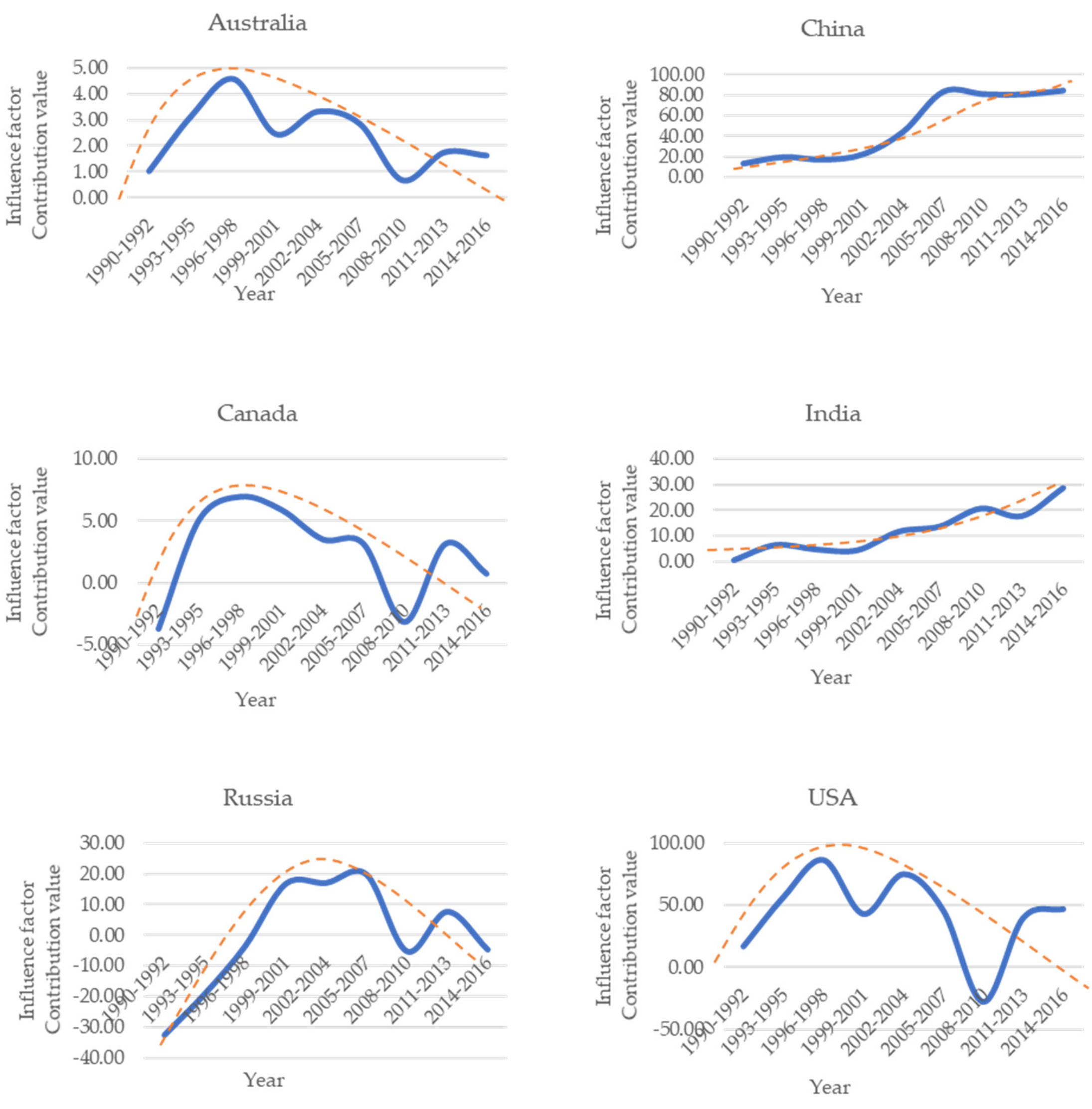

Figure 7. Effect values of the economic output effective for the six Asia-Pacific countries.

From the overall results, the value of the economic output effect (DG, Table 5) and its contribution rate (B_{GD}, Table 6) in each period of the six countries from 1990 to 2016 are greater than the other effects. This indicates that the economic output effect is the main influencing factor for the growth of the road transportation industry's carbon emissions. According to the calculation, the values of the economic output effect for China, Australia, and the United States from 1990 to 2016 are 606.64, 31.96, and 540.90, respectively, whose respective contribution rates are 90.83%, 127.76%, and 128.22%. The results indicate that the economic output effects of China, Australia, and the United States have greater influences on carbon emissions of the road transportation industry than other countries. This reveals that the economic output effects of the three countries still have a relatively large space to decline.

4.2.2. Transportation Intensity Effect

Most of the effect values (DR, Table 5) are negative in the transportation intensity effects from China, Russia, and the United States to carbon emissions of road transportation industry in each stage. This indicates that the transportation intensity effects of the three countries present negative driving forces of carbon emissions of the road transportation industry. India's has a positive driving effect. The reason is that the development of India's manufacturing industry and the improvement of people's living standard leads to increasing traffic. Thus, the growth rate of road freight volume and passenger volume exceeds that of GDP, bringing an increase of transportation intensity. However, Australia's and Canada's have no significant influence, which shows that for China, Russia, and the United States, the transportation intensity effect is an important factor to curb the growth of carbon emissions, while for India, measures need to be taken to reduce the transportation intensity and the influences of transportation intensity effect on the growth of carbon emissions.

4.2.3. Energy Intensity Effect

There are some differences in the influences of energy intensity effect (DP, Table 5) on carbon emissions of the road transportation industry in the six countries. Overall, Australia, the United States, India, and Canada play negative roles in their energy intensity effects driving carbon emissions of the road transportation industry, while China and Russia act as positive driving roles. Since the 1990s, the slow promotion of Chinese vehicle energy saving technology and the increasing requirements of enterprises on the speed, as well as efficiency of transportation, make a gradual rise in energy consumption intensity of Chinese operating road transportation vehicles. Hence, this finally leads to the rise of energy intensity for China's road transportation industry. Therefore, it shows that China's energy intensity effect has a positive influence on carbon emissions of the road transportation industry.

During the study period, the contribution rates in 1990–2016 (B_{DP}, Table 6) of the energy intensity effect in Canada and Russia are, respectively, −122.83% and −512.81%. This indicates that the energy intensity effect of the two countries is the main influencing factor in reducing carbon emissions of the road transportation industry. China's contributes at a rate of 24.23% to carbon emissions of the road transportation industry, ranking first among all countries. This indicates that the energy intensity effect on carbon emissions has a positive effect.

4.2.4. Carbon Emissions Coefficient Effect

It can be seen from Tables 5 and 6 that the values of the carbon emissions coefficient effect (B_{DS}, Table 5) for the six countries are all less than 4, and the contribution rates of the carbon emissions coefficient effect are less than 9%. So, the carbon emissions coefficient effect has a relatively small influence on the carbon emissions of the road transportation industry for the six countries.

4.2.5. Population Size Effect

It can be seen from Table 6 that, except for Russia, most values of the population size effect (DO, Table 5) for the other five countries in each period are positive. This indicates that the population size effect plays a positive driving role in the carbon emissions of the road transportation industry. The effect value of the Russian population size effect is negative, mainly due to the decline of their population in the research period—and the decline is obvious in that their population decreased by 2.44% in 2016 compared with that in 1990, with a total of 3.59 million people.

5. Conclusions and Suggestions

5.1. Conclusions

This paper uses the LMDI decomposition model to analyze the carbon emissions and driving factors of the road transportation industry for six Asia-Pacific countries. It comes to the following main conclusion that an overall rise is seen in the carbon emissions of the road transportation industry of the six Asia-Pacific countries from 1990 to 2016. In 2016, the total carbon emissions of the road transportation industry in the six Asia-Pacific countries reached 2961.37 million tons compared with that in 1990, with a growth of 84.42%. Among them, the carbon emissions of the road transportation industry for the United States accounted for 54.24% of the total volume of that in the six Asia-Pacific countries in 2016, ranking highest among them; China was second with 24.60%, and Australia came in last with only 2.78%. Among the driving factors, the economic output and population size effects play positive driving roles in the road transportation industry; the economic output effect is the main factor for their increasing carbon emissions. However, the transportation intensity effect and the energy intensity effect, being divergent to some degree in different countries, have negative driving effects on the carbon emissions of the road transportation industry in most countries. Where the transportation intensity effect of India plays a positive driving role in the carbon emissions of the road transportation industry, contributing with a rate of 78.47%, the energy intensity effects of China and Russia also play positive driving roles in the carbon emissions. The carbon emission coefficient effect has a relatively small influence on the carbon emissions of the road transportation industry in the six countries—and, except Russia, the population size effect of the other five countries plays a positive role in driving the carbon emissions of the road transportation industry.

5.2. Policy Suggestions

The United States, which accounts for more than half of the total carbon emissions from the six Asia-Pacific countries, withdrew from Paris Agreement in 2017. This signaled that the United States did not want to fulfill its international obligations to reduce carbon emissions. The international community should exert pressure on them to change their attitude towards carbon emissions control. China is second only to the United States in carbon emissions of the road transportation industry, and has made some progress in carbon emissions in recent years. However, the rising energy intensity restricts its achievement of carbon emissions control. China should make policies, such as accelerating the promotion of new energy vehicles and improving vehicle emissions standards, etc., to reduce the energy intensity of road transportation industry. The carbon emissions of the Indian road transportation industry are growing relatively fast. Therefore, India should reduce its transportation intensity and control its carbon emissions growth by controlling the carbon emissions of transportation in the process of developing manufacturing industry.

Compared with 1990, Russia is the only one of the six Asia-Pacific countries whose carbon emissions from the road transportation industry decreased in 2016. However, the age of Russian road operating vehicles is generally older, which leads to its rising energy intensity in the road transportation industry since 1990. Russia should reduce this energy intensity and promote its carbon emissions to fall faster by formulating policies such as accelerating the elimination of old cars. Since 2005, the carbon emissions of the road transportation industry in Canada have begun to slow down, and since 2014, its carbon emissions have shown a negative growth. So, Canada can lower its carbon emissions by reducing its transportation intensity. Australia witnesses a relatively slow growth in its carbon emissions of the road transportation industry, and a relatively good result in its carbon emissions control. Therefore, it can be improved from the aspect of reducing transportation intensity next.

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Appendix A

In this section, we give the calculation process of the LMDI method. To this end, it follows from Formula (4) that:

$$\ln C = \ln G + \ln R + \ln P + \ln S + \ln O$$

Therefore:

$$\ln C^t - \ln C^0 = \ln \frac{G^t}{G^0} + \ln \frac{R^t}{R^0} + \ln \frac{P^t}{P^0} + \ln \frac{S^t}{S^0} + \ln \frac{O^t}{O^0} \tag{A1}$$

Let $\Delta C = C^t - C^0$.

Then, we can rewrite ΔC as follows:

$$\Delta C = \frac{C^t - C^0}{\ln C^t - \ln C^0}\left(\ln C^t - \ln C^0\right)$$

Furthermore, by Formula (A1), we have:

$$\Delta C = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \left[\ln \frac{G^t}{G^0} + \ln \frac{R^t}{R^0} + \ln \frac{P^t}{P^0} + \ln \frac{S^t}{S^0} + \ln \frac{O^t}{O^0}\right]$$

Let:

$$\begin{gathered} DG = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln \frac{G^t}{G^0}; DR = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln \frac{R^t}{R^0}; \\ DP = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln \frac{P^t}{P^0}; DS = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln \frac{S^t}{S^0}; \\ DO = \frac{C^t - C^0}{\ln C^t - \ln C^0} \cdot \ln \frac{O^t}{O^0} \end{gathered}$$

Then:

$$\Delta C = C^t - C^0 = DG + DR + DP + DS + DO$$

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