Factor analysis of changes in CO2 emissions in China

Ye Zuoyi (Shanghai International of
Business and Economics)
FUJIKAWA Kiyoshi (Aichi Gakuin University)

ASSIA Working Paper Series 22-02

October, 2022

Applied Social System Institute of Asia (ASSIA)
Nagoya University

名古屋大学 アジア共創教育研究機構

Factor analysis of changes in CO_2 emissions in China

YE Zuoyi [*] and FUJIKAWA Kiyoshi [†]

Table of Contents

List of Tables

List of Figures

* Department of International Business, Shanghai International of Business and Economics E-mail: yzuoyi@suibe.edu.cn
† Faculty of Economics, Aichi Gakuin University. E-mail: fujikawa@dpc.agu.ac.jp

Factor analysis of changes in CO_2 emissions in China

YE Zuoyi and FUJIKAWA Kiyoshi

Summary

This study clarified the factors behind the change in carbon dioxide (CO_2) emissions in China using the deviation from proportional growth (DPG) analysis, which is an application of input−output analysis. The target periods include 2007–2012 and 2012–2017.

The factors of consumption and investment were positive, and the export factor was negative throughout each as factors for changes in output in each industry. In the second period, the consumption factor expanded rapidly and became overwhelmingly positive; however, the investment factor shrank. The Chinese economy has changed from export-led to domestic demand-led, and even among domestic demand, it has changed to consumption-led. The major factors behind the change in CO_2 emissions were the CO_2 reduction effect due to changes in technology and emissions coefficients throughout both periods; the power and heat supply industry had a large negative impact, and power saving in other Chinese industries also progressed. Comparing the first and second periods indicated that the negative magnitude of DPGs of CO_2 emissions in all industries expanded in the second period, and energy-saving accelerated in each industry.

Abbreviation

CEDS	Carbon Emission Accounts & Datasets
COP	Conference of the Parties
GHG	greenhouse gas
NDCs	Nationally Determined Contributions
SDA	structural decomposition analysis
DPG	deviation from proportional growth

1. Introduction

One of the most urgent challenges facing humanity today is global warming, the leading cause of which is the consumption of fossil fuels in our daily lives and production activities. At the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change in Paris in 2015, it was proposed that participating countries should reduce greenhouse gas (GHG) emissions to limit the temperature rise less than 2°C, preferably to 1.5°C by the end of this century. Participating countries announced their own voluntary goals, NDCs (Nationally Determined Contributions), and mutually recognized these as the "Paris Agreement" to achieve this goal; however, the World Meteorological Organization (2022) estimates that the post-industrial temperature rise will reach 1.5°C between 2022 and 2026. To prevent global warming, it is necessary to urgently promote efforts toward a low-carbon society in both developed and developing countries.

China's economy has developed rapidly, bringing a swift upsurge in energy consumption. China's carbon dioxide (CO_2) emissions surpassed the United States in 2006 to become the world's largest; as of 2021, China's CO_2 emissions are twice those of the United States. Consequently, the Chinese government, formerly inactive regarding curbing energy consumption, has changed its policy in recent years. The NDC submitted by China to the COP21 Paris conference set a goal of reducing CO_2 emissions by 2030 and reducing CO_2 emissions per GDP by 60%−65% of the 2005 levels. At the United Nations General Assembly on September 22, 2020, China's President Xi Jinping announced that China would strive to achieve carbon neutrality by 2060.

Global warming is closely related to energy consumption structure, and planning effective global warming countermeasures requires understanding the relationship between the economic structure of both supply and demand, energy consumption, and CO_2 emissions. This study clarifies the factors behind recent changes in China's industrial structure and examines how these changes are related to changes in energy demand and CO_2 emissions. For this purpose, this research uses input−output tables.

2. Literature review

Input−output tables are economic statistics that comprehensively record the flow of goods and services. Reading an input−output table in the row direction indicates the demand structure; a certain industry's output is demanded by what industries as intermediate goods and in what form the final demand (consumption, investment, or export). Conversely, reading an input−output table in the column direction indicates the cost structure: which industries supply intermediate goods and what kind of added value (wages, profits, or indirect taxes) is generated for the output of a specific industry. By incorporating data, such as natural resource inputs or environmental pollutant emissions, input−output tables become powerful analytical tools for understanding the relationship between economic activities and resources or the environment.

Some studies use input−output tables to analyze the factors behind changes in industrial structure, energy consumption, and CO_2 emissions. Many of these studies used structural decomposition analysis (SDA), which decomposes intertemporal changes in the output of each industry into several factors. There are two types of SDA: 1) one that directly analyzes changes in the output level and 2) one that analyzes the extent of deviation after assuming that the output of each industry changes at the same rate. This study focuses on China, which has proliferated; in the case of such an economy, if we use the first method where changes in the level are analyzed, all factors would be positive, making it challenging to identify the main factors. Therefore, this study uses the second method that adjusts the scale of the intertemporal economy. This method would more appropriately be called a factor analysis of economic structural changes rather than a factor analysis of output changes.

Research on factor analysis concerning this kind of economic structural change began with the deviation from proportional growth analysis proposed by Chenery (1960). Chenery (1960) used the gross domestic product (GDP) growth rate as the proportional growth rate, defining growth industries as those with faster growth rates than the proportional growth rate and industries with slower growth rates as declining. Several demand factors explain the deviation from proportional growth defined in this way. This method is called the deviation from proportional growth (DPG) analysis. Although Chenery (1960) did not use an input−output table, this research method became an applied field of input−output analysis and produced many successors. Chenery et al. (1962) analyzed changes in Japan's economic structure from 1914 to 1954, concluding that the growth factors of growth industries were technological change (increase in intermediate demand) and import substitution. Fujikawa (1999) conducted a long-term analysis of the Japanese economy from 1914 to 1990, showing that exports replaced investment as the driving force behind changes in the industrial structure after 1970 and that a service economy exists in both intermediate and final demands in Japan. Fujikawa (1999) also analyzed the structure change in South Korea from 1960 to 1990, stating that exports drove changes in the industrial structure from the beginning of development.

SDAs targeting the Chinese economy in the early stages of the reform and opening-up policy concluded that the main factors in China's industrial structural change were import substitution, exports, and technological change (Fujikawa and Ninomiya, 1997; Teng Jian, 1997; Chen and Guo, 2000; Kim and Hasebe, 2006). Newer studies have found that exports, investment, and technological change contributed to the change in industrial structure (Jiang, 2008; Li, 2015; Ye and Fujikawa, 2016); however, the evaluation of private consumption is divided. For example, Jiang (2008) indicates that private consumption is a factor in the expansion, but Li (2015) and Ye and Fujikawa (2016) suggest otherwise.

Concerning the SDA on China's CO_2 emissions, Hasebe (1995) focused on 1987 to 1990, arguing that although the effects of private investment and private consumption were minor, the positive factors of intermediate inputs and exports were significant, resulting in significant increases in CO_2 emissions from the Chinese economy as a whole. Fujikawa (1997) focused on 1981 to 1992 and found that although the economy's overall CO_2 emissions increased, the first half of the study period showed a negative effect of intermediate inputs, while the second half indicated that private consumption and private investment had a negative effect. Peters et al. (2007) focused on China from 1992 to 2002, and Guan (2009) focused on the period from 2002 to 2005. These studies show that while CO_2 emissions increase mainly due to urbanization (infrastructure construction) and expanding consumption in urban areas due to lifestyle changes, reductions due to technological changes and improvements in energy efficiency were marginal. Zhang (2010) focused on changes in industrial structure and CO_2 emissions from 1992 to 2002, attributing the increase in CO_2 emissions to the manufacturing sector's rapid development. Peng et al. (2015) conducted a factor analysis of changes in CO_2 emissions from 1995 to 2009, finding that CO_2 emissions increased due to the expansion of exports and final domestic demand; however, the CO_2 emissions reduction effect due to technological change was negligible. Liao and Xu (2017) conducted a factor analysis of CO_2 emissions from 2007 to 2012, finding that CO_2 emissions increased due to the expansion of final demand, and the reduction effect due to improvements in energy efficiency and changes in the input structure was not significant.

These studies concluded that technological change and improvement in energy efficiency had little effect on changes in CO_2 emissions in China, but the most recent situation in China was not reflected. After the 11th Five-Year Plan for National Economic and Social Development covering 2006−2010, the Chinese government started full-scale efforts to improve the utilization efficiency of resources and energy and protect the environment. Therefore, this paper estimates the connected input−output table for 2007−2012−2017 and follows Fujikawa's method (1997) to conduct an SDA on changes in China's industrial structure and CO_2 emissions.

3. Model and data

3.1. DPG analysis on output

This section introduces a model formula that applies DPG analysis, a method of assuming a hypothetical situation in which all industries have changed at the same growth rate and explaining the divergence between this and the actual inter-industry structure (this is the deviation from proportional growth). In the input−output framework, changes in production technology (changes in input coefficients), changes in final demand, and changes in the import ratio explain deviations from proportional growth.

α represents the growth ratio (proportional ratio) of the total output from the first to the second period, and the DPG of each industry is defined as follows:

$$\Delta\mathbf{x} = \mathbf{x}_2 - \alpha\mathbf{x}_1 \qquad (1)$$

where $\mathbf{x}_1$ and $\mathbf{x}_2$ represent the output in the first and second periods, respectively. DPG analysis decomposes the DPG defined in this way into various demand factors using the input-output analysis framework. The supply and demand balance equation for the first period can be expressed as follows:

$$\mathbf{x}_1 = (\mathbf{I} - \widehat{\mathbf{M}}_1)\mathbf{A}_1\mathbf{x}_1 + (\mathbf{I} - \widehat{\mathbf{M}}_1)\mathbf{d}_1 + \mathbf{e}_1 \qquad (2)$$

where $\widehat{\mathbf{M}}_1$is a diagonal matrix with the import ratio and $\mathbf{A}_1$は is an input coefficient matrix. $\mathbf{d}_1, \mathbf{e}_1$ vectors represent final domestic demand (the sum of consumption, capital investment, and the net increase in inventories) and exports, respectively. Domestic demands are converted to demands for domestically produced goods by multiplying $(\mathbf{I} - \widehat{\mathbf{M}}_1)$ from the left side; however, note that all exports are assumed to be domestically produced, so no import coefficient is multiplied. Solving equation (2) for output $\mathbf{x}_1$ yields the following equation for determining equilibrium output:

$$\mathbf{x}_1 = [\mathbf{I} - (\mathbf{I} - \widehat{\mathbf{M}}_1)\mathbf{A}_1)]^{-\mathbf{1}}[(\mathbf{I} - \widehat{\mathbf{M}}_1)\mathbf{d}_1 + \mathbf{e}_1] \qquad (3)$$

Following the same method, the equation for determining equilibrium output can be obtained for the second period.

$$\mathbf{x}_2 = [\mathbf{I} - (\mathbf{I} - \widehat{\mathbf{M}}_2)\mathbf{A}_2)]^{-\mathbf{1}}[(\mathbf{I} - \widehat{\mathbf{M}}_2)\mathbf{d}_2 + \mathbf{e}_2] \qquad (4)$$

Substituting equations (3) and (4) into equation (1), we obtain the following model equation that explains the DPG.

$$\Delta\mathbf{x} = \mathbf{B}_2(\mathbf{I} - \widehat{\mathbf{M}}_2)\Delta\mathbf{d} + \mathbf{B}_2\Delta\mathbf{e} + \mathbf{B}_2(\widehat{\mathbf{M}}_1 - \widehat{\mathbf{M}}_2)\alpha(\mathbf{A}_1\mathbf{x}_1 + \mathbf{d}_1 + \mathbf{e}_1)$$
$$+\mathbf{B}_2(\mathbf{I} - \widehat{\mathbf{M}}_2)(\mathbf{A}_2 - \mathbf{A}_1)\alpha\mathbf{x}_1 \qquad (5)$$

where $\mathbf{B}_2 = [\mathbf{I} - (\mathbf{I} - \mathbf{M}_2)\mathbf{A}_2]^{-\mathbf{1}}$ expresses the Leontief inverse matrix in the second period. The first and second terms on the right-hand side are the DPG. The first results from the fact that the growth rate of final domestic demand differed from that of the total output, and the second term is the DPG resulting from the fact that the growth rate of export differed from that of the total output. The third term is the DPG resulting from changes in import coefficients (changes in import dependency), and the fourth is the DPG resulting from changes in input coefficients (technological change).

3.2. DPG analysis on CO_2 emissions

DPG of CO_2 emissions of each industry can be divided into production and emission coefficient (CO_2 emissions per output) factors.

$$\Delta\mathbf{c} = \mathbf{c}_2 - \boldsymbol{\alpha}\mathbf{c}_1 = \mathbf{p}_2\mathbf{x}_2 - \mathbf{p}_1\boldsymbol{\alpha}\mathbf{x}_1 = \mathbf{p}_2(\mathbf{x}_2 - \boldsymbol{\alpha}\mathbf{x}_1) + (\mathbf{p}_2 - \mathbf{p}_1)\boldsymbol{\alpha}\mathbf{x}_1 \qquad (6)$$

where $\mathbf{c}$ and $\mathbf{p}$ stand for CO_2 emissions and emission coefficient, respectively. The first term on the right-hand side is the effect of changes in domestic output, and the second is the effect of changes in emission coefficient. $(\mathbf{x}_2 - \boldsymbol{\alpha}\mathbf{x}_1)$ in the first term on the right-hand side is the DPG of domestic output; thus, substituting equation (5) into equation

(6) can decompose equation (6) into the factors of changes in demand items and changes in technological structure, as shown in equation (7).

$$\Delta\mathbf{c} = \mathbf{p}_2\mathbf{B}_2(\mathbf{I}-\widehat{\mathbf{M}}_2)\Delta\mathbf{d} + \mathbf{p}_2\mathbf{B}_2\Delta\mathbf{e} + \mathbf{p}_2\mathbf{B}_2(\widehat{\mathbf{M}}_1-\widehat{\mathbf{M}}_2)\alpha(\mathbf{A}_1\mathbf{x}_1 + \mathbf{d}_1 + \mathbf{e}_1)$$
$$+\mathbf{p}_2\mathbf{B}_2(\mathbf{I}-\widehat{\mathbf{M}}_2)(\mathbf{A}_2-\mathbf{A}_1)\alpha\mathbf{x}_1 + (\mathbf{p}_2-\mathbf{p}_1)\boldsymbol{\alpha}\mathbf{x}_1 \quad (7)$$

The DPG total of all industries is zero in the case of DPG of output, but in the case of CO_2 emission DPG, each industry's total is not zero. A positive DPG on CO_2 emissions indicates that structural changes resulted in higher CO_2 emissions relative to output. Conversely, a negative DPG on CO_2 emissions indicates that structural changes resulted in lower CO_2 emissions relative to output.

3.3. Data

The input−output tables published in China in 2007, 2012, and 2017 are nominal. It is necessary to create a link input−output table with fixed prices to exclude the effects of prices and compare industrial structure changes over time. The China Statistical Yearbook (CSY) figures were used as price data, and the CO_2 emission coefficients (CO_2 emissions per output) by industry were obtained from CEADs. The industrial classification of these statistics is not the same as the industrial classification of the input−output table; therefore, it was necessary to adjust the industrial classification among statistics. Table 1 shows the correspondence between the input−output table and the CO_2 emission coefficient data by industry classification. After adjusting the industrial classifications, the input−output table used in this study has 28 sectoral classifications.

We recalculated the 2007 base price index since the CSY carries a chain price index with the previous year's price set to 100. For the prices of agriculture, forestry, and fisheries, we used the CSY Agricultural Product Producer Price Index. When the mining and manufacturing sectors' industry classification of the price data in the CSY matches that in the input−output table, unaltered CSY prices are used. When the sector classification of the input−output table is rougher than that of the CSY price index, we used the weighted average of the CSY price data with the weight of the output in the input−output table. Furthermore, we used the Construction and Interior Works Price Index in CSY for the price of the construction sector and the Consumer Price Index in CSY for transportation, postal services, telecommunications, commerce, lodging, restaurants, and other services. With the industry-specific prices created above, we created a fixed price time series input−output table for 2007, 2012, and 2017, using 2007 as the base year. We also used the domestic goods' prices for imports and exports.

Table 1 Industry classification correspondence table

NO	CO_2 Emissions Database (CEADs)	NO	Input-Output table with 42 sectors	NO	Aggregated Input-Output table with 28 sectors
1	Agric, forestry & fisheries	1	Agric, forestry & fisheries	1	Agric, forestry & fisheries
2	Coal	2	Coal	2	Coal
3	Crude oil & natural gas	3	Crude oil & natural gas	3	Crude oil & natural gas
4 5	Iron ore Nonferrous mining	4	Metal mining	4	Metal mining
6 7	Non-metallic mining Other mining	5	Non-metallic mining	5	Non-metallic mining
9 10 11 12	Processed Food Food Processing Beverage Tobacco	6	Food &Tobacco	6	Food & Tobacco
13 24	Fiber Chemical fiber	7	Fiber	7	Fiber
14 15	Clothing Leather	8	Clothing & Leather	8	Clothing & Leather
8 16 17	Logging out Wood processing Furniture	9	Wood processing & furniture	9	Wood processing & furniture
18 19 20	Papermaking Printing Stationary	10	Papermaking, printing & stationary	10	Papermaking & printing
21	Petroleum & coal prods	11	Petroleum & coal prods	11	Petroleum & coal prods
22 23 25 26	Chemical Products Pharmaceuticals Rubber product Plastic products	12	Chemical industry	12	Chemical industry
27	Ceramic & clay	13	Ceramic & clay	13	Ceramic & clay
28 29	Iren & steel Nonferrous metal	14	Primary metal	14	Primary metal
30	Metal products	15	Metal products	15	Metal products
31 32	General machinery Special machinery	16 17	General machinery Special machinery	16	General machinery
33	Transport machinery	18	Transport machinery	17	Transport machinery
34	Electric machinery I	19	Electric machinery	18	Electric machinery
35	Electronic & comm eqp	20	Electronic & comm eqp	19	Electronic & comm eqp
36	Precision equipment	21	Precision equipment	20	Precision equipment
37 38	Other manufacturing Waste disposal	22 23 24	Other manufacturing Waste disposal Machine repair	21	Other manufacturing
39	Power & heat supply	25	Power & heat supply	22	Power & heat supply
40	Gas prod & supply	26	Gas prod & supply	23	Gas prod & supply
41	Water supply	27	Water supply	24	Water supply
42	Construction	28	Construction	25	Construction
43	Transport, postal service & Communication	30 32	Transport & postal service Communication	26	Trans & Comm
44	Commerce & restaurant	29 31	Commerce Hotel & restaurant	27	Commerce & restaurant
45	Other services	33 34 35 36 37 38 39 40 41 42	Finance Real estate Rental business Scientific research Public management Personal service Education Public health Culture, Sports & Ent Public administration & Social security	28	Other services

Source: Authors' compilation based on CEADs (Carbon Emission Accounts & Datasets) https://www.ceads.net/ and China Input−output table 200, 2012, and 2017.

4. Changes in China's industrial structure

4.1 Growth source of the macroeconomy

The average growth rate in the first period of 2007−2012 (α_1) was 1.71, and that in the second period of 2012−2017 (α_2) was 1.38.

Figure 1 shows the results of DPG analysis on the macroeconomy. Investment, import substitution, and consumption were the main positive factors in the first half, while exports and technological change were the negative factors. In the second period, consumption, investment, and import substitution were the main positive factors, while technological change and exports were negative.

The positive and negative factors patterns were the same in both periods; however, the figures' magnitude changed considerably. The positive effect of consumption expanded rapidly in the second period. Although investment was a positive factor, its magnitude decreased from the first period, when the world economy experienced stagnation due to the global economic crisis originating in the United States in 2008 (known as the Lehman shock in Japan) and the European debt crisis in 2009 (known as the Euro crisis in Japan). As a result, the Chinese economy struggled to continue its export-driven economic growth.

Nonetheless, the Chinese government expanded public investment (infrastructure investment, capital investment in key industries) to support the economy[1] and adopted a low interest-rate policy, leading to a real estate investment boom[2]. Additionally, tax cuts on passenger cars started in 2015, stimulating investment and consumption in the private sector, and the expansion of Internet sales has increased personal consumption.

---

[1] The domestic demand expansion policy announced by the Chinese government is known as the four trillion CNY large-scale economic stimulus package. See Japan External Trade Organization (2009) for details. Four trillion CNY is about 600 billion USD as of 2008.

[2] Please see Section 2: Response to global excess production capacity, Capter2, Part II, of the White Paper on International Economy and Trade 2018.

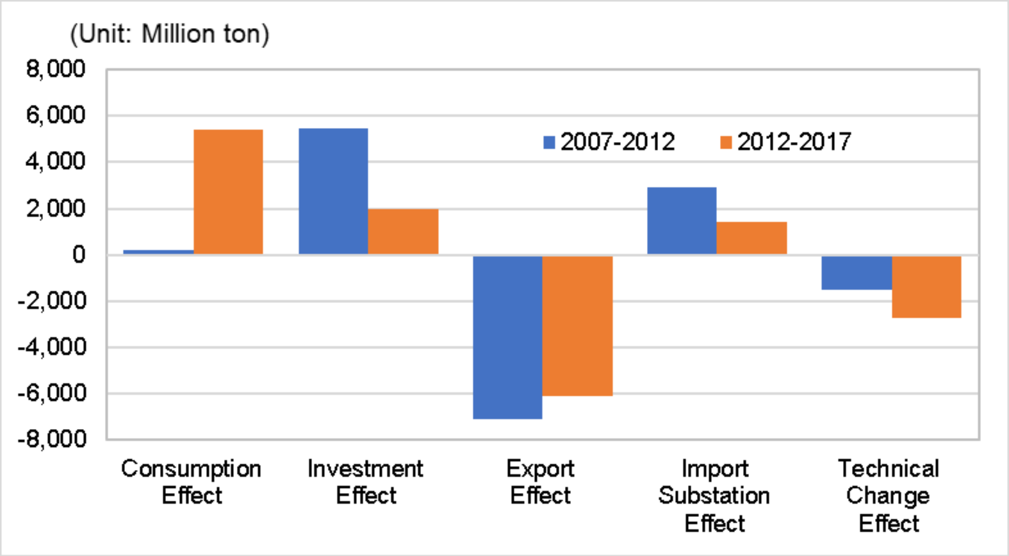

Figure 1 DPG analysis on output (macro)

Source: Created by authors

4.2. DPG analysis on output 2007–2012

Table 2 shows the results of the DPG analysis from 2007 to 2012 (first period). As already mentioned, China's exports during this period were sluggish due to the global financial crisis; however, the Chinese government made large-scale infrastructure investments and capital investments in key industries to stimulate the economy. Therefore, investment was the major positive factor (5,464 billion CNY) for industrial structural changes during this period, followed by import substitution (2,925 billion CNY) and consumption (222 billion CNY). The largest negative factor was the export effect (7,101 billion CNY), followed by technological change (1,510 billion CNY).

Looking at the results by industry, DPG was positive in manufacturing industries, such as transport equipment, chemical industry, electrical machinery, electronic and communication equipment, paper manufacturing and printing, and primary metals, with growth industries concentrated in the machinery industry. Among them, the size of the DPG for transportation machinery stands out, driven by investment effects, import substitution, and consumption. In the non-manufacturing sector, the DPG for transportation, warehousing and communication, commerce and restaurant, and other services was significantly positive, driven by investment and technological change. Since technological change was particularly positive, we understand that the Chinese economy has begun to shift to a service-oriented economy (increased demand for services as an intermediate input). On the other hand, the DPG of agriculture, forestry, and fisheries was significantly negative, and the factors behind this were the adverse effects of consumption and technological change. The DPG of textiles was also significantly negative, mainly due to the decrease in exports.

Table 2 DPG analysis on output by industry (2007–2012)

(α = 1.71; Unit: Billions CNY)

	Industry	DPG	Cons	Inv	Export	Import Sub	Tech Change
1	Agric, forestry & fisheries	−2,238.9	−912.8	95.3	−422.2	−27.0	−972.3
2	coal	−194.5	16.8	56.3	−95.6	−78.9	−93.0
3	Crude oil & natural gas	−742.8	42.2	54.8	−40.0	−411.5	−388.3
4	metal mining	−23.5	4.5	27.9	−73.2	15.3	2.0
5	non−metallic mining	−276.9	−1.0	−1.0	−21.4	8.2	−261.6
6	Food & Tobacco	320.3	7.0	61.5	−270.9	42.2	480.6
7	Fiber	−1,520.0	−71.4	19.6	−1,562.6	104.3	−9.9
8	Clothing & Leather	−27.0	−34.2	20.3	154.7	−22.9	−145.0
9	Wood processing & furniture	−183.9	34.3	−48.2	−95.7	−2.1	−72.1
10	Papermaking & printing	190.6	157.9	141.4	161.8	47.0	−317.4
11	Petroleum & coal prods	−962.2	109.0	151.7	−108.3	33.4	−1,148.1
12	Chemical industry	489.0	148.3	196.8	−984.4	897.7	230.6
13	Ceramic & clay	102.9	−23.1	31.1	−19.8	49.3	65.4
14	Primary metal	123.4	46.1	448.9	−623.1	155.5	95.8
15	Metal products	−62.5	−6.5	196.5	−233.7	89.2	−108.2
16	General machinery	124.7	40.3	657.0	−58.5	437.6	−951.7
17	Transport machinery	711.4	319.4	1,086.5	−88.6	20.5	−626.4
18	Electric machinery	361.7	46.8	179.5	−180.7	319.5	−3.5
19	Electronic & comm eqp	225.0	86.8	49.1	−589.8	499.1	179.8
20	Precision equipment	−281.3	−0.2	−28.6	−411.6	275.5	−116.4
21	Other manufacturing	−1,238.2	−179.1	−96.9	−240.1	−219.3	−502.8
22	Power & heat supply	−1,057.4	85.1	135.7	−233.2	71.4	−1,116.4
23	Gas production & supply	59.4	54.7	13.6	−5.3	2.0	−5.5
24	Water supply	−57.6	13.1	2.1	−4.0	1.2	−70.0
25	Construction	197.8	−159.0	25.5	−25.1	27.7	328.6
26	Trans & Comm	1,127.1	199.2	980.5	−366.1	38.6	274.9
27	Commerce & restaurant	465.0	−438.9	303.9	11.5	113.2	475.3
28	Other services	4,368.4	636.9	702.9	−675.6	438.3	3,265.9
	Total	−0.0	222.4	5,463.8	−7,101.4	2,924.9	−1,509.8

Source：Authors’ calculation

4.3 DPG analysis on output 2012−2017

Table 3 shows the results of the DPG analysis for 2012−2017 (second period). Consumption was the largest positive factor (5,382 billion CNY) for industrial structural changes during this period, followed by investment (1,994 billion CNY) and import substitution (1,447 billion CNY). Before the Lehman shock, China's exports were brisk, and the accompanying investment was the engine of growth; however, economic environments changed in China after the Lehman shock. The large−scale economic stimulus package of four trillion CNY and the low interest rate policy ended in 2010, after which China's economic policy shifted to a tightening one. In the latter period (2012−2017), the effects of the large−scale economic stimulus measures diminished, and the loan interest rate remained relatively high (approximately 6%). Therefore, the excess production capacity created by the economic stimulus measures became a problem[3]. Consumption replaced investment as the center of economic growth. During

[3] Please see Section 2: Response to global excess production capacity, Capter2, Part II, of the White Paper on International Economy and Trade 2018.

this period, the Chinese economy was at a turning point from export-led to domestic demand-led, and within domestic demand, from investment-led to consumption-led. Conversely, technological change (−2,729 billion CNY) was the largest negative factor, followed by exports (−6,094.1 billion CNY).

Looking at the results by industry, DPG was negative in most manufacturing sectors; the electronic and communication equipment sector had the only relatively large positive figure. DPG was also positive in precision equipment, food and tobacco, and other manufacturing; however, the magnitude was marginal. In contrast, China's real estate investment boom continued, and the construction industry's DPG proliferated. Other industries with positive DPGs included other services, transportation and communications, and commerce and restaurants. In addition to the consumption effect, technological change was significant in these industries, and China's economy became increasingly service-oriented.

Table 3 DPG analysis of output by industry (2012−2017)

(α = 1.38; Unit: Billions CNY)

Industry	DPG	Cons	Inv	Export	Import Sub	Tech Change
1 Agric, forestry & fisheries	−1,291.0	2.0	−528.6	−130.1	−24.6	−609.8
2 coal	−342.7	26.0	36.3	−50.2	28.9	−383.7
3 Crude oil & natural gas	109.4	45.2	26.9	−40.2	96.8	−19.2
4 metal mining	−350.9	10.5	−4.3	−36.3	−83.1	−237.7
5 non−metallic mining	22.1	2.9	53.4	−8.4	−5.0	−20.7
6 Food & Tobacco	247.7	925.0	−150.0	−160.9	−103.7	−262.8
7 Fiber	−1,005.1	−74.5	−62.3	−352.9	−25.6	−489.8
8 Clothing & Leather	−476.2	−145.0	−4.5	−372.1	−45.6	91.0
9 Wood processing & furniture	−85.7	57.0	110.7	−63.4	−47.2	−142.7
10 Papermaking & printing	−184.6	148.0	−8.5	−217.9	35.1	−141.4
11 Petroleum & coal prods	−560.2	114.0	101.0	−83.2	46.3	−738.4
12 Chemical industry	−949.9	375.8	93.6	−582.9	−164.4	−672.1
13 Ceramic & clay	−50.3	10.4	529.9	−102.9	15.9	−503.6
14 Primary metal	−4,120.8	98.9	−30.9	−348.6	166.3	−4,006.5
15 Metal products	−78.5	37.4	−80.4	−145.9	45.4	65.1
16 General machinery	−1,888.9	71.5	−1,665.9	−367.6	34.1	38.9
17 Transport machinery	−129.0	453.1	−584.4	−356.1	87.3	271.1
18 Electric machinery	−685.2	−38.1	−465.2	−286.6	63.0	41.7
19 Electronic & comm eqp	1,204.0	256.6	−76.5	−965.4	1,163.7	825.6
20 Precision equipment	102.2	18.9	−47.5	−39.9	76.6	94.0
21 Other manufacturing	96.0	18.3	−8.7	−14.5	142.1	−41.2
22 Power & heat supply	−809.6	54.1	75.4	−149.3	16.1	−806.0
23 Gas production & supply	112.9	14.5	5.7	−6.0	0.3	98.5
24 Water supply	−9.4	−8.3	5.2	−2.8	0.3	−3.8
25 Construction	2,003.0	10.5	2,273.6	−25.2	−13.6	−242.3
26 Trans & Comm	4,108.1	1,001.4	1,248.7	−171.2	−9.4	2,038.7
27 Commerce & restaurant	1,053.9	99.5	86.2	−487.5	−77.3	1,432.9
28 Other services	3,958.9	1,796.5	1,065.5	−526.3	27.8	1,595.3
Total	0.0	5,382.2	1,994.2	−6,094.1	1,446.6	−2,728.8

Source: Authors' calculation

5. Changes in China's CO_2 emission structure

5.1. Source of changes in China's CO_2 emissions

Figure. 2 shows the results of the DPG analysis on the CO_2 emissions. During the first period (2007−2012), the economy expanded 1.7 times; simultaneously, CO_2 emissions increased no more than 1.4 times from 6.2 billion tons to 8.7 billion tons. The increase rate in CO_2 emissions is lower than that in output, indicating that energy efficiency improved. Technological change and changes in emission coefficients explain a significant part of the energy intensity improvement. CO_2 emissions increased due to consumption, investment, and import substitution; however, those impacts were limited. In addition, during the second period (2012−2017), while the economic scale expanded 1.4 times, CO_2 emissions increased slightly from 8.7 billion to 8.9 billion tons. As in the first half, technological change and changes in emission factors were the primary sources.

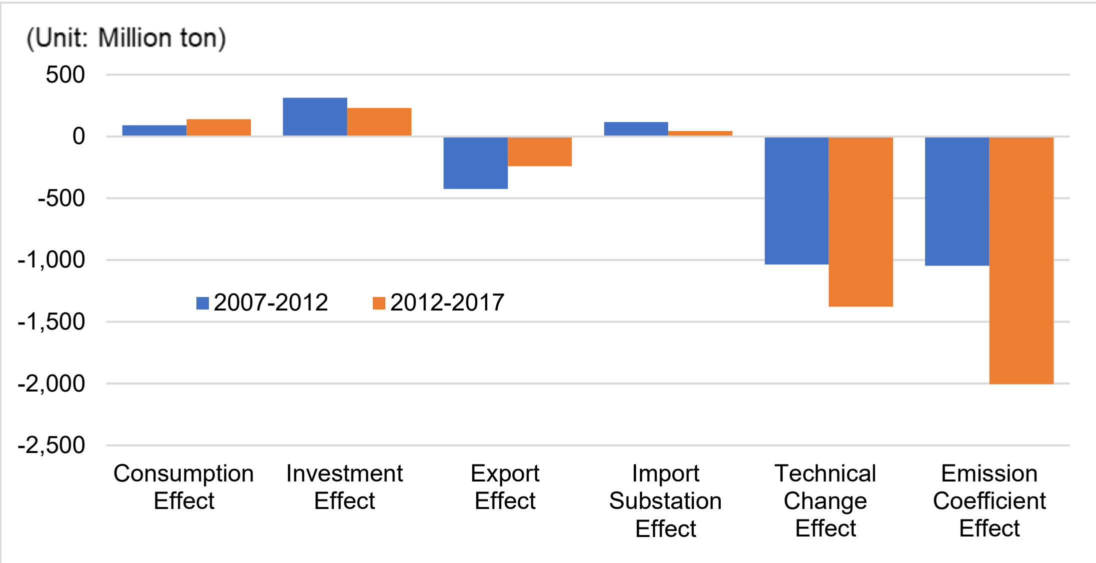

Figure 2 DPG analysis on CO_2 emissions (macro)

Source: Created by authors

5.2. DPG analysis on CO_2 emissions 2007−2012

Table 4 shows the results of the DPG analysis on CO_2 emissions during 2007−2012; the GDPs in CO_2 emissions were mainly negative due to changing emission factors (−1 billion tons) and technological changes (−1 billion tons).

Regarding the results by industry, the DPG of CO_2 emissions was negative in all industries except coal. Notably, the reduction in CO_2 emissions from electricity and heat supply is extremely large among such industries. Technological change was the primary source of the negative DPG of electricity and heat supply, suggesting that energy conservation (especially power saving) has progressed in each industry in China. It is also noteworthy that electricity and heat supply account for most technological change factors for reducing CO_2 emissions. In the manufacturing sectors, the negative DPG of CO_2 emissions is (negatively) large in industries like primary metals, ceramic and clay, and chemical industries, and the primary source for this is the decrease in the emission coefficients. Like the previous section, in the non-manufacturing sectors, such as transportation and communications, commerce and restaurants, and other services, the DPG on output was positive due to the increase in demand; however, the decrease in the emission coefficient is large enough to offset it, resulting in the DPG in CO_2 emissions of these sectors becoming negative.

Table 4 DPG analysis of CO_2 emissions by Industry (2007−2012)

Unit: Millions ton

	Industry	DPG	Cons	Inv	Export	Import Sub	Tech Change	Emi Coeff
1	Agric, forestry & fisheries	−45.5	−13.5	1.4	−6.2	−0.4	−14.4	−12.5
2	coal	8.2	1.4	4.8	−8.2	−6.8	−8.0	24.9
3	Crude oil & natural gas	−33.0	2.0	2.6	−1.9	−19.6	−18.5	2.4
4	metal mining	−2.3	0.1	0.4	−1.2	0.2	0.0	−2.0
5	non-metallic mining	−8.2	−0.1	−0.1	−1.4	0.5	−17.1	9.9
6	Food & Tobacco	−64.2	0.1	0.8	−3.6	0.6	6.4	−68.5
7	Fiber	−45.7	−1.0	0.3	−21.3	1.4	−0.1	−24.9
8	Clothing & Leather	−10.9	−0.1	0.1	0.5	−0.1	−0.5	−10.8
9	Wood processing & furniture	−8.5	0.3	−0.4	−0.7	−0.0	−0.5	−7.1
10	Papermaking & printing	−31.6	2.8	2.5	2.8	0.8	−5.6	−35.0
11	Petroleum & coal prods	−50.0	5.8	8.1	−5.7	1.8	−60.9	1.0
12	Chemical industry	−155.2	3.9	5.2	−26.0	23.7	6.1	−168.1
13	Ceramic & clay	−299.1	−7.2	9.7	−6.2	15.4	20.4	−331.1
14	Primary metal	−325.7	7.6	73.5	−102.1	25.5	15.7	−345.9
15	Metal products	−10.3	−0.0	1.2	−1.4	0.5	−0.7	−9.9
16	General machinery	−40.3	0.3	4.5	−0.4	3.0	−6.6	−41.2
17	Transport machinery	−11.3	1.2	4.2	−0.3	0.1	−2.4	−14.0
18	Electric machinery	−11.4	0.1	0.3	−0.3	0.6	−0.0	−12.1
19	Electronic & comm eqp	−9.2	0.1	0.0	−0.4	0.3	0.1	−9.4
20	Precision equipment	−1.5	−0.0	−0.1	−0.9	0.6	−0.3	−0.9
21	Other manufacturing	−2.5	−1.4	−0.7	−1.9	−1.7	−3.9	7.1
22	Power & heat supply	−605.9	75.5	120.4	−207.0	63.4	−991.1	332.9
23	Gas production & supply	−8.9	0.4	0.1	−0.0	0.0	−0.0	−9.3
24	Water supply	−0.3	0.1	0.0	−0.0	0.0	−0.3	−0.0
25	Construction	−14.8	−0.6	0.1	−0.1	0.1	1.2	−15.5
26	Trans & Comm	−124.5	13.7	67.3	−25.1	2.7	18.9	−201.8
27	Commerce & restaurant	−27.3	−4.4	3.1	0.1	1.1	4.8	−32.0
28	Other services	−42.9	4.3	4.8	−4.6	3.0	22.3	−72.7
	Total	−1,982.7	91.3	314.2	−423.5	116.8	−1,035.0	−1,046.5

Source: Authors' calculation

5.3. DPG analysis on CO_2 emissions 2012−2017

Table 5 shows the results of the DPG analysis of CO_2 emissions during 2012−2017, which were also negative, and the factors were the same as in the first period, mainly due to changing emission factors (−2 billion tons) and technological changes (−1.4 billion tons).

Regarding the results by sector, the DPG of CO_2 emissions was negative in all industries, including the coal industry. As in the first period, the large negative DPG of power and heat supply was noted. In addition to the negative factor of technological change in this industry's first period, the emission coefficient factor also became negative in the second period. The fact that the factor of emission coefficient in the electricity and heat supply sector was negative means that the source for power generation has become low-carbonized. The significant negative DPG of CO_2 emissions in the manufacturing sector was recorded in primary metals, ceramic and clay, and the chemical industry. Again, technological change and a decline in emission coefficients were the factors behind this, indicating that the decarbonization of the entire intermediate input structure has progressed further.

Table 5 DPG analysis of CO_2 emissions by Industry (2012−2017)

Unit: Millions ton

	Industry	DPG	Cons	Inv	Export	Import Sub	Tech Change	Emi Coeff
1	Agric, forestry & fisheries	−16.7	0.0	−8.0	−2.0	−0.4	−9.2	2.8
2	coal	−104.2	1.1	1.5	−2.1	1.2	−15.7	−90.2
3	Crude oil & natural gas	−19.5	1.3	0.8	−1.2	2.8	−0.6	−22.7
4	metal mining	−13.0	0.1	−0.0	−0.3	−0.7	−2.1	−9.9
5	non−metallic mining	−19.7	0.1	1.5	−0.2	−0.1	−0.6	−20.3
6	Food & Tobacco	−67.6	6.2	−1.0	−1.1	−0.7	−1.8	−69.2
7	Fiber	−34.4	−0.5	−0.4	−2.3	−0.2	−3.2	−27.9
8	Clothing & Leather	−10.1	−0.2	−0.0	−0.4	−0.1	0.1	−9.5
9	Wood processing & furniture	−12.9	0.1	0.2	−0.1	−0.1	−0.3	−12.8
10	Papermaking & printing	−38.7	1.1	−0.1	−1.7	0.3	−1.1	−37.3
11	Petroleum & coal prods	−57.9	5.0	4.4	−3.7	2.0	−32.5	−33.3
12	Chemical industry	−148.1	6.7	1.7	−10.4	−2.9	−12.0	−131.1
13	Ceramic & clay	−559.3	2.2	112.7	−21.9	3.4	−107.1	−548.6
14	Primary metal	−664.7	16.3	−5.1	−57.4	27.4	−660.2	14.4
15	Metal products	−15.2	0.1	−0.2	−0.4	0.1	0.2	−15.0
16	General machinery	−38.8	0.3	−5.9	−1.3	0.1	0.1	−32.1
17	Transport machinery	−21.2	0.7	−0.8	−0.5	0.1	0.4	−21.0
18	Electric machinery	−9.5	−0.0	−0.3	−0.2	0.0	0.0	−9.1
19	Electronic & comm eqp	−2.3	0.1	−0.0	−0.3	0.4	0.3	−2.7
20	Precision equipment	−1.1	0.0	−0.0	−0.0	0.1	0.1	−1.1
21	Other manufacturing	−3.2	0.1	−0.0	−0.0	0.5	−0.1	−3.5
22	Power & heat supply	−1,189.8	43.2	60.1	−119.0	12.8	−642.4	−544.4
23	Gas production & supply	−1.6	0.0	0.0	−0.0	0.0	0.2	−1.8
24	Water supply	−0.5	−0.0	0.0	−0.0	0.0	−0.0	−0.5
25	Construction	−6.4	0.0	6.2	−0.1	−0.0	−0.7	−11.9
26	Trans & Comm	−74.8	46.0	57.4	−7.9	−0.4	93.7	−263.7
27	Commerce & restaurant	−27.6	0.7	0.6	−3.4	−0.5	9.9	−34.9
28	Other services	−47.6	8.5	5.0	−2.5	0.1	7.5	−66.3
	Total	−3,206.6	139.2	230.4	−240.4	45.2	−1,377.0	−2,003.9

Source: Authors' calculation

6. Concluding remarks

This paper analyzed the factors behind the change in China's industrial structure and how such change relates to changes in CO_2 emissions.

We compiled fixed−price time series input−output tables for 2007−2012 and 2012−2017 based on the input−output tables published by the National Bureau of Statistics and applied the DPG analysis, which is a method that assumes a proportional growth economy in which each industry grows at the same rate, and decomposes the difference between the actual and proportional growth into various demand factors. The results obtained are summarized as follows.

First, consumption and investment were positive, and technological change and exports were negative factors in both periods. Later (2012−2017), the consumption factor expanded rapidly and became overwhelmingly positive. Conversely, although the investment factor was positive, the magnitude decreased. The Chinese economy was well known as an export−led economy; however, it changed from export−led to domestic demand−led, with a recent shift from investment−led to consumption−led.

Second, the leading growth industries in the first period (2007−2012) were transportation, chemical, electrical, and machinery industries, such as electronic and communication equipment. The factors were consumption, investment, and import substitution. In contrast, in non−manufacturing industries, transportation, communications, and other services expanded; however, growth industries shifted from manufacturing to service industries in the second period (2012−2017). Notably, technological change significantly affected the service industry's expansion, and the economy's service orientation is also progressing in China.

Finally, the DPG of CO_2 emissions was almost negative during both periods. The DPG of CO_2 was negative in energy-intensive industries such as primary metals, ceramic and clay, chemicals, petroleum and coal products, and non-energy-intensive manufacturing and service industries. The main drivers of the change were (energy-saving) technology change and emission factor change. Regarding the changes by industry, the electric power and heat supply industry recorded a significant negative figure, indicating that energy conservation (power saving) has progressed in the Chinese economy. Comparing the first (2007−2012) and second periods (2012−2017), the negative range of CO_2 emission DPG in the second expanded in each industry, confirming the acceleration of energy-saving technology changes.

References

Chen Xikang and Guo Jue (2000), “Chinese Economic Structure and SDA model,” *Journal of System Science and System Engineering*, 19(2), 142-148.

Chenery B. Hollis (1960), “Patterns of Industrial Growth,” *American Economic Review*, 50(4), 624-654.

Chenery B. Hollis, Shishido Shuntaro. and Watanabe Tsunehiko (1962), “The Pattern of Japanese Growth, 1914−1954,” *Econometric*a, 30, 98−39.

Fujikawa Kiyoshi (1996), “Industrial Structural Change and its Factors: Experiences in Japan, Korea and Taiwan,” *Business Economy*, Institute of small business research and business administration, Osaka University of Ecoboimics. 31, 88─116. (in Japanese)

Fujikawa Kiyoshi (1997), “An Analysis of China's Economic Growth and Energy /Environmental Issues」, Econometric approach to environmental problems, Ch1, Part1, *Economic Analysis*, 154, Economic and Social Research Institute. (in Japanese) < https://www.esri.cao.go.jp/jp/esri/archive/bun/bun154/bun154a.pdf >

Fujikawa Kiyoshi and Ninomiya Shoji (1997), “Changes in China's industrial structure and their factors,” *Journal of Osaka University of Economics*, 47(6), 45-90.

Guan Dabo, Peters Glen, Weber Christopher, and Hubacek Klaus (2009) “Journey to world top emitter: An analysis of the driving forces of China's recent CO_2 emissions surge,” *Geophysical Research Letters*, 36(4). <https://doi.org/10.1029/2008GL036540>

Hasebe Yuichi (1995), “Changes of Chinese economic structure and environmental load,” *Economia*, Yokohama National University, 46(3), 52-64. (in Japanese) <https://ynu.repo.nii.ac.jp/index.php?action=pages_view_main&active_action=repository_action_common_download&item_id=2074&item_no=1&attribute_id=20&file_no=1&page_id=59&block_id=74>

Japan External Trade Organization (JETRO)(2009), Economic Stimulus Measures by the Chinese Government and Their Effects, Business Opportunities and Risks for Japanese Companies, Overseas Research Department, JETRO, (In Japanese) <https://www.jetro.go.jp/ext_images/jfile/report/07000102/urgent-report_china090813.pdf>

Jiang Tao (2008), “The SDA Analysis of Industrial Development in Transitional China”, *Review of Industrial Economics,* Shandong University, 7(3), 115−132. (in Chinese) <https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CCJD&dbname=CCJDLAST1&filename=CYJP200803010&uniplatform=NZKPT&v=o7RtqQIFE6arxbhqIro7Sad692BEk4WLdKLV6qUXse-NY5YBGnpsedKw5JJJVcJ3>

Jin Jihong and Hasebe Yuichi (2006), “The factor analysis of the economic structure change in China: an analysis based on constant price I-O tables,” *Economia*, Yokohama National University, 57(2), 19-28. (in Japanese) <https://ynu.repo.nii.ac.jp/?action=repository_uri&item_id=2117&file_id=20&file_no=1>

Li Bo (2015), “Influences of Industrial Structural Change on Growth of Chinese Economy from a Viewpoint of Inter−industrial Relationships,” *Regional Economic Studies*, Hiroshima University, 26, 29-40. (in Japanese) < https://cres.hiroshima−u.ac.jp/kiyou/26/26_03.pdf >

Liao Mingqiu and Xu Leiming (2017), “IO-SDA Model of CO_2 Emissions and its Empirical Research”, *Statistical Research,* 34(7), 62−70. (in Chinese) < https://tjyj.stats.gov.cn/CN/10.19343/j.cnki.11-1302/c.2017.07.006>

Ministry of Economy, Trade and Industry（2018）, *White Paper on International Economy and Trade 2018*. < https://www.meti.go.jp/english/report/data/wp2018/wp2018.html>

Pan Jiahua, Phillips Jonathan and Chen Ying (2008),"China's Balance of Emissions Embodied in Trade: Approaches to Measurement and Allocating International Responsibility," *Oxford Review of Economic* Policy, 24(2), 354-376. <https://doi.org/10.1093/oxrep/grn016>

Peng Shuijun, Zhang Wencheng and Sun Chuanwang (2015), "China's Production-Based and Consumption-Based Carbon Emissions and Their Determinants", *Economic Research Journal,* 50(01), 168−182. (in Chinese) <http://www.erj.cn/en/IssueInfo.aspx?m=20150821085059340239>

Peters Glen, Weber Christopher, Guan Dabo, and Hubacek Klaus (2007), "China's Growing CO_2 Emissions: A Race between Increasing Consumption and Efficiency Gains," *Environmental Science & Technology*, 41(17), 5939-5944. <https://doi.org/10.1021/es070108f>

Teng Jian (1997), "Factor Analysis of China's Economic Growth and Industrial Structural Change," *Asia Keizai*, Institute of Developing Economies, 38(2), 44-61. (in Japanese)

World Meteorological Organization（2022）, "Global Annual to Decadal Climate Update" <https://hadleyserver.metoffice.gov.uk/wmolc/WMO_GADCU_2022−2026.pdf>

Ye Zuoyi, Jin Jihong, and Fujikawa Kiyoshi (2016), "Changes in China's industrial structure and their factors,", in Fujikawa Kiyoshi (ed), *Input Output Analysis and Applied General Equilibrium Analysis on the Chinese Economy*, Ch1, 3-18, Horitsu Bunka Sha. (in Japanese)

Zhang Youguo (2010), "Supply-Side Structural Effect on Carbon Emissions in China," *Energy Economics*, 32(1), 186-193. <https://doi.org/10.1016/j.eneco.2009.09.016>

Statistical Data

CO_2 Emissions

Carbon Emission Accounts & Datasets. <https://www.ceads.net/data/nation/>

Price by industry

National Bureau of Statistics, *China Statistical Yearbook* 2008-2019, China Statistics Press.
<https://spc.jst.go.jp/statistics/stats_index.html>

Input Output Table

National Bureau of Statistics (ed) (2009) *China Input Output Table 2007*, China Statistics Press.

National Bureau of Statistics (ed) (2015) *China Input Output Table 2012*, China Statistics Press.

National Bureau of Statistics (ed) (2019) *China Input Output Table 2017*, China Statistics Press.