Productivity and Eco-Efficiency of Chinese Industry

Watanabe Takatoshi (Aichi Gakuin University)
Fujikawa Kiyoshi (Aichi Gakuin University)

ASSIA Working Paper Series 22-07

March, 2023

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

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Watanabe Takatoshi*
Fujikawa Kiyoshi†

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*Faculty of Economics, Aichi Gakuin University. E-mail : twata@dpc.agu.ac.jp
†Faculty of Economics, Aichi Gakuin University. E-mail : fujikawa@dpc.agu.ac.jp

Abstract

This paper estimates the growth rate of total factor productivity (TFP) by the industrial sector in China during the early 2000s and examines the relationship between TFP growth and improvements in energy efficiency and reductions in CO_2 emissions. The estimation periods were 2002–2007 and 2007–2012, and the level of TFP growth was generally positive in both periods. However, if we take transportation machinery and electronics and telecommunications equipment as the leading sectors of the Chinese economy, relatively high TFP growth rates of 1.75% and 1.26%, respectively, were estimated for the first period, but they declined considerably to 1.11% and 0.01%, respectively, in the second period. The decline in the TFP growth rate in the second period may be attributed to the impact of the Lehman Brothers collapse. The global recession reduced demand for exports; however, China's economic stimulus measures, which included large-scale public investment, may have led to an excess of capital.

Regarding the relationship between TFP and energy efficiency, it was observed that the higher the TFP growth rate, the higher the energy productivity of the industry. However, no clear correlation was found between the TFP growth rate and CO_2 emissions. This may be because, in this study, the CO_2 emissions were assumed to be the direct emissions of the industry in question. In the next study, we will attempt an analysis that also considers indirect CO_2 emissions generated during power generation.

Keywords

CO_2 emissions
Energy efficiency
Input–Output Table
Total Factor Productivity (TFP)

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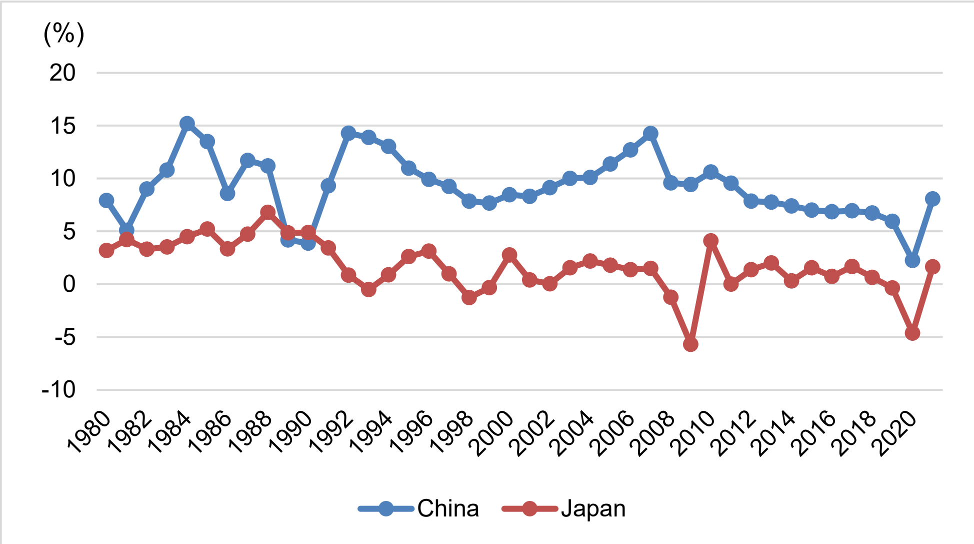
1. Introduction

China's full-fledged economic growth began with the adoption of the Reform and Open Door Policy in 1978. This policy, which was promoted by then Vice President Deng Xiaoping for the introduction of capital and technology from abroad, was a modification of Mao Zedong's self-reliance policy. However, this policy of reform and liberalization has not always been well implemented. In the 1980s, immediately after the introduction of the Reform and Open Door Policy, there was an investment boom in China from developed countries, and the Chinese economy grew rapidly. However, this movement was suppressed by the Chinese government, which does not tolerate political freedom, resulting in the tragedy of the Tiananmen Square incident. The suppression of political freedom also reflected a sense that communism would be undermined by the economic power of the West among Chinese conservatives. Developed countries condemned the incident and imposed economic sanctions. As a result, foreign investment in China plummeted.

Figure 1 shows the economic growth rates of Japan and China. In 1989, there was a sharp decline in China's economic growth rate due to conservative modifications to the Reform and Open Door Policy. However, the southern provinces, where economic growth was beginning to take off, were dissatisfied with these backward steps. In response to these developments, Deng Xiaoping toured the south of China in 1992 and reemphasized the concept of a "socialist market economy" that guarantees freedom of economic activity (the so-called "Southern Tour Discourse"). The pro-reform and open-door movement once again took control of China's economic management as a result of this. Foreign investment then began to surge, and China once again recorded double-digit economic growth.



Source: IMF - World Economic Outlook Databases

Figure 1 GDP growth in Japan and China

Undoubtedly, the Reform and Open Door Policy was the catalyst for China's "takeoff," and while there was a debate among China researchers in the 1990s about the "quality" of this economic growth, the World Bank (1993, 1997) evaluated the policy as a success and made optimistic forecasts that China's growth would continue. In contrast, Krugman (1994) argued that the high economic growth rates in the early years of economic development in socialist countries were due to the increased mobilization of factors of production and not increased productivity. Furthermore, he pessimistically predicted that China's production expansion would not be long-lasting.

However, if we look back at Japan's past experience, Japan's industrial structure became more sophisticated through the introduction of technology from advanced Western countries, and during the high-growth period, improvements in productivity emerged as the primary source of economic growth (Saito (2000)). In addition, it is widely recognized that the end of the high-growth period was partly attributable to the narrowing of the technology gap between Japan and the Western industrialized countries in the early 1970s. Given that China's economy has also achieved economic growth by leveraging foreign capital and technology, it is natural to expect that China will follow the same process as Japan in the years to come.

While there are numerous different assessments of the growth of the Chinese economy during the 1980s and 1990s, Fujikawa and Watanabe (2005) used the periods 1987–1992 and 1992–1997 to estimate the rates of productivity growth in different industries in China. Krugman's (1994) assertion was, in part, unfounded;

while the increases in TFP in the 1980s were not observed to be significant, as will be discussed below, a large TFP growth area was observed in the 1990s, particularly in the industrial sectors. Much as was the case in Fujikawa and Watanabe (2005), one of the objectives of this study is to estimate productivity growth by the industrial sector in China in the 2000s. In other words, we will examine whether industries with higher productivity growth rates were also improving their energy efficiency and reducing their CO_2 emissions.

In the following sections of this study, Section 2 describes the model used in this paper to estimate productivity growth rates, and Section 3 introduces previous research on production in China. Section 4 presents the estimated results for China's productivity by industry, followed by a discussion of the relationship between the TFP growth rate and eco-efficiency in Section 5. Section 6 provides an interpretation of these estimates, and Section 7 presents our conclusions.

2. Model

Following Solow (1957) and Denison (1967), it is widely recognized that the growth of productivity is one of the most important factors for economic growth. There are various measurement methods for productivity growth depending on the form of the aggregation function of the inputs. The trans-log function, i.e., the quadratic function of the logarithm, is now frequently used. A trans-log function is defined in Eq. (1), where the amount of output is denoted by $Y$and the amount of the *i*th input is denoted by $X_i, (i = 1, \cdots, n)$.

$$ln\, Y = a_0 + \sum a_{1i}\, ln\, X_i + \sum\sum a_{2ij}\, ln\, X_i \cdot ln\, X_j \qquad (1)$$

As the trans-log production function is a quadratic function, the growth of output from period 0 to period 1 can be defined as follows, using the quadratic lemma:

$$ln\, Y_1 - ln\, Y_0 = \frac{1}{2}\sum_i \left(\frac{\partial\, ln\, Y_1}{\partial\, ln\, X_{1i}} + \frac{\partial\, ln\, Y_0}{\partial\, ln\, X_{0i}}\right)(ln\, X_{1i} - ln\, X_{0i}) \qquad (2)$$

Or,

$$ln\, Y_1 - ln\, Y_0 = \frac{1}{2}\sum_i \left(\frac{X_{1i}}{Y_1}\frac{\partial Y_1}{\partial X_{1i}} + \frac{X_{0i}}{Y_0}\frac{\partial Y_0}{\partial X_{0i}}\right)(ln\, X_{1i} - ln\, X_{0i}) \qquad (2)'$$

China's economic system is not necessarily based on the principle of profit maximization under conditions of perfect competition. However, if we could apply the marginal theory that assumes each input's real wage to be equal to its marginal productivity, Equation (2)" can be transformed as follows:

$$ln\, Y_1 - ln\, Y_0 = \frac{1}{2}\sum_i \left(\frac{X_{1i}}{Y_1}\frac{q_{1i}}{p_1} + \frac{X_{0i}}{Y_0}\frac{q_{0i}}{p_0}\right)(ln\, X_{1i} - ln\, X_{0i}) \qquad (3)$$

Or,

$$ln\,Y_1 - ln\,Y_0 = \frac{1}{2}\sum_i (w_{1i} + w_{0i})\,(ln\,X_{1i} - ln\,X_{0i}) \qquad (3)'$$

In the above-described equations, the symbols p and q_i are the prices of the output and the *i*th input, respectively, and w_i is the nominal input share of the *i*th input.

This equation states that, as long as the form of the production function is unchanged, the growth rate of output is the same as the weighted average of the growth rate of each input, where the weights are determined by each input's nominal share. However, the equality in Equation (3)' does not necessarily hold when the observed data are substituted in because the shape of the production function usually varies with changes of time. Therefore, we define the difference between the left-hand side and the right-hand side of the equation as caused by efficiency change. That is to say, when the left-hand side is larger, the cause is an efficiency improvement. Equation (4) is the definition of the 'growth of Total Factor Productivity (TFP).

$$TFP = (ln\,Y_1 - ln\,Y_0) - \frac{1}{2}\sum_i (w_{1i} + w_{0i})\,(ln\,X_{1i} - ln\,X_{0i}) \qquad (4)$$

3. Previous research on TFP in China

3-1 Previous research covering the period up to the 1990s

Young's (1994) work estimated the TFP growth rates for four newly industrializing countries (NIEs), namely, Hong Kong, Singapore, South Korea, and Taiwan, and compared them with the results of Elias's (1990) (for South American countries) and Christensen et al. (1980) (for developed countries). Similar to Krugman (1994), this study argued that the economic growth of newly industrializing Asian countries was generally a "factor of production mobilization type" and "these TFP growth rates are neither higher than those of South American countries nor greater than the past experience of advanced economies."" Young (2003) subsequently estimated China's TFP growth rate using self-adjusted data. The author stated that the TFP growth rate of the industrial sectors was about half (1.4%) of that estimated using official data (3.0%) when adjusted data were used and stated that while a TFP growth rate of 1.4% is certainly large, it is not surprisingly so.

Table 1 Comparison of TFP growth rates in Asia, developed countries, and Latin America

Developing countries	Period	Annual rate (%)	Advanced countries	Period	Annual rate (%)
Hong Kong	1966-91	2.3	Canada	1947-73	1.8
Singapore	1966-90	- 0.3	France	1950-73	3.0
South Korea	1966-90	1.6	West Germany	1950-70	3.7
Taiwan	1966-90	1.9	Italy	1952-73	3.4
Argentina	1940-80	1.0	Japan	1952-73	4.1
Brazil	1950-80	2.0	Netherlands	1951-73	2.5
Chile	1940-80	1.2	Britain	1955-73	1.9
Colombia	1940-80	0.9	The USA	1947-73	1.4
Mexico	1940-80	1.7			

Source: Young(1994)

Furthermore, Table 2 shows the results of the World Bank (1997) estimates. As shown in the right column of Table 2, the share of the effects of input growth and technological progress among the factors contributing to China’s economic growth from 1978 to 1995 was 7:3. This is comparable to the TFP growth rates of Japan, the U.S., and South Korea. This result implies that China’s TFP growth rate after reform and liberalization was 2.73% per year, which is a relatively high figure.

Table 2 World Bank comparison of TFP growth rates for China, Japan, the U.S., and South Korea

Country	Period	Average annual growth rate (%)				Factor share (%)	
		GDP	Capital equipment	Human capital	Labor force	Inputs	Technological change
China	1978–95	9.4	8.8	1.6	2.4	71	29
USA	1950–92	3.2	3.2	1.1	1.6	65	35
Japan	1960–93	5.5	8.7	0.3	1.0	70	30
South Korea	1960–93	8.6	12.5	3.5	2.4	79	21

Source: World Bank (1997)

Fujikawa and Watanabe (2005) estimated productivity growth rates by industrial sector for China using data for the period 1987–1997. Their estimation results are shown in Table 3. The growth rate of output in each industry was reasonably high in both periods; however, the TFP growth rate underlying this was clearly different between the two periods. In the period 1987–1992, little TFP growth was observed, and Krugman’s (1994) assertion may have been true for China at that time. In the period 1992–1997, however, improvements in TFP expanded in the machinery industry, including in transportation machinery and electrical equipment, as technologies from abroad were actively introduced, and it can no longer be argued that the economy grew solely by mobilizing total factors of production [1].

Table 3 TFP growth in China by industrial sector

1987-92	Output Growth	Contribution of inputs			TFP growth
		Int. inputs	Labor	Capital	
10 Metals	7.84	10.24	0.84	0.76	-5.61
11 General Machinery	12.15	10.22	1.04	0.41	1.44
12 Trans. Equipment	20.28	17.64	0.91	0.73	3.37
13 Elec. Appliances	11.37	9.30	0.95	0.61	1.43
14 Other Manufacturing	22.51	20.04	1.11	1.16	2.87
15 Construction	5.97	3.04	2.24	0.25	0.88
16 Elec. Gas & Water	15.39	11.92	0.26	6.04	-1.32
17 Transportation	6.06	9.83	0.71	2.77	-10.92
18 Trade & Catering	22.88	19.80	3.94	1.21	1.15
19 Services	11.91	11.36	2.29	2.69	-4.82
Average	10.35	9.07	1.13	1.00	-0.34
1992-97	Output Growth	Contribution of inputs			TFP growth
10 Metals	10.42	10.36	0.06	0.33	-0.31
11 General Machinery	9.35	4.75	-0.44	0.21	5.61
12 Trans. Equipment	22.10	18.91	0.59	0.65	4.96
13 Elec. Appliances	22.74	19.64	0.21	0.87	5.06
14 Other Manufacturing	19.99	9.55	0.60	0.42	13.19
15 Construction	10.54	12.96	0.94	0.13	-5.43
16 Elec. Gas & Water	4.28	10.38	-0.03	1.52	-12.33
17 Transportation	14.81	5.21	1.08	2.45	8.75
18 Trade & Catering	5.22	3.68	1.98	0.84	-1.11
19 Services	11.31	8.25	2.35	1.36	0.58
Average	11.75	9.46	0.27	0.72	2.31

Source: Fujikawa and Watanabe(2005)

3-2 Previous research covering the 2000s and subsequent years

Wu and Liang (2017) found a substantial TFP growth rate of 1.86% in the 1980s, as shown in Table 4, which they mainly attributed to agricultural reforms (mainly the introduction of market forces in rural areas). While the TFP growth rate in the 1990s was sluggish at 0.72% due to a lack of progress in the reform of state-owned enterprises, the TFP growth rate for the period up to the collapse of Lehman Brothers was also estimated to be high. This was attributed to the increase in exports following the country's accession to the WTO in 2001.

[1] Fujikawa and Watanabe (2005) examined the relationship between TFP growth in the Chinese economy and the introduction of foreign capital and export activities of foreign-invested firms and confirmed that the larger the share of foreign-invested firms, the higher the TFP growth rate of the industry in question, and the higher the TFP growth rate of an industry, the higher its export share in total sales. It was verified that, in the 1980s and 1990s, foreign-invested enterprises in China played a role in raising the productivity of export industries and boosted export-led economic growth.

However, after the collapse of Lehman Brothers, the TFP growth rate turned negative from 2007 to 2012.

Table 4 The Lehman Brothers collapse: China's TFP growth rate

	Value-added growth	Capital input (%)	Labor input (%)	TFP(%)
1981-1991	8.81	5.82	1.12	1.86
1991-2001	8.85	7.00	1.12	0.72
2001-2007	11.37	9.45	0.59	1.32
2007-2012	9.22	10.39	0.25	-1.42

Source: Wu and Liang (2017)

Brandt et al. (2020) estimated TFP in China before and after the collapse of Lehman Brothers in 2008 and found that the TFP growth rate was 3.5% from 1979 to 1988, immediately after the adoption of the Reform and Open Door Policy, and 2.8% from 1999 to 2008, prior to the Lehman Brothers collapse, which was remarkably high. However, the growth rate significantly declined to 0.7% in the period 2009–2018 following the crisis. It was pointed out that although the Chinese economy continued to grow even after the global financial crisis, the main reason for this was an increase in capital from public investment and the limited contribution of TFP.

Wei et al. (2020) estimated the TFP for China from 1979 to 2015 and found that the main factor contributing to the growth of the Chinese economy was an increase in capital, with only a limited contribution from a quantitative increase in labor. Moreover, the TFP growth was positive until 2008 (before the Lehman Brothers crisis) but turned negative thereafter. The aggressive fiscal policy after the collapse of Lehman Brothers stimulated capital accumulation but did not lead to structural reforms to increase efficiency, which is similar to the assessment of Brandt et al. (2020).

What these studies have in common is that they find that the TFP growth rate declined after the collapse of Lehman Brothers and the ensuing crisis. As discussed below, these results are consistent with the results presented in this paper. The reasons for this will be discussed below.

4. Estimated TFP by industrial sector in China

4-1. Data used

This study uses three connected input–output tables for China for the years 2007, 2012, and 2017. To make the production and input volumes comparable over time, we created a Linked Input-Output Tables (real table) from these three input–output tables, valued at 2007 prices [2]. Price coefficients from the China

[2] For details, please refer to Chapter 4 of YE and Fujikawa (2023).

Statistical Yearbook were used for the price data. For the industrial sector classification, the production sectors (columns) were merged into 28 sectors, and the intermediate input sectors (rows) were merged into two sectors: energy and non-energy. Production factors are defined as labor and capital. The labor input was calculated using the China Population & Employment Statistics Yearbook, and the capital input was calculated using the capital depletion allowance in the input–output table. However, since the capital depreciation allowance is a nominal value, it was converted to real 2007 prices using the fixed capital investment price index in the China Statistical Yearbook[3].

4-2. Estimated TFP growth by industrial sector in China

The estimation period for the TFP growth rate in this paper covers 2007–2017 and is split into two: the first (2007–2012) and second halves (2012–2017) of the period. In the first half of 2008, China's economy was in the midst of the global recession triggered by the collapse of Lehman Brothers, and export-led economic growth was showing signs of faltering. Therefore, in the fall of 2008, the Chinese government announced a 4 trillion RMB stimulus package (public investment) to compensate for the decline in foreign demand. In the second half of the period, the Chinese economy began to transition from having a foreign-demand-led structure to one that is driven by domestic demand (consumption)-led economic growth. As represented by the terms "new normal" and "moderately prosperous society," the Chinese economy at this time was facing the challenge of shifting from a period of high economic growth to one of stable growth and beyond.

(1) TFP growth rate from 2007 to 2012

Table 5 shows the TFP growth rates (%) by industry for the first half of the period. The shaded cells in the table for output and TFP represent the top five industry sectors. The average increase in output was as high as 9.0% across all industries. The industrial sectors with particularly high rates of increase were gas production and supply, other services, and transportation and communication, all of which are services sectors. In the industrial sector, transport machinery and electric machinery were the top exporters, while papermaking and printing, chemical industry, and electronic and communication equipment also showed high growth rates.

The rate of increase in TFP was estimated to be generally positive, averaging 1.3% across all industries. The high TFP growth rates were estimated in other manufacturing and transpor machinery in the manufacturing industry, and in

[3] This is not the ideal method but due to data limitations, this method was used as the best available solution.

commerce and restaurant, and other services in the service industry. The rate of increase in TFP is defined as the difference between the rate of change in output and the rate of change in the factors of production, and labor input was found to be the main contributor to the rate of increase in TFP. Underlying the increase in TFP in many industries was a decrease in labor input due to improvements in labor efficiency.

Table 5 TFP growth in China by industrial sector (2007–2012)

Unit：%

Industry		Output	Material inputs	Energy inputs	Labor inputs	Capital inputs	TFP
1	Agric, forestry & fisheries	3.97	2.92	0.10	-2.09	0.16	2.88
2	Coal	7.18	4.18	2.90	0.25	0.57	-0.71
3	Crude oil & natural gas	-1.36	1.73	-0.84	-1.78	0.65	-1.13
4	Metal mining	8.69	6.25	0.57	-0.11	0.76	1.22
5	Non−metallic mining	-0.08	-0.22	0.25	-0.51	-0.00	0.41
6	Food & tobacco	9.62	7.55	0.07	0.24	0.18	1.60
7	Fiber	2.03	1.51	-0.02	-0.75	0.02	1.28
8	Clothing & leather	8.89	7.38	0.07	0.04	0.25	1.15
9	Wood processing & furniture	7.52	6.16	0.10	-0.29	0.44	1.11
10	Papermaking & printing	10.01	7.96	0.31	0.32	0.40	1.02
11	Petroleum & coal prods	4.22	1.62	4.08	-0.11	0.03	-1.40
12	Chemical industry	9.64	7.84	0.49	0.33	0.32	0.66
13	Ceramic & clay	9.38	7.59	0.95	1.88	0.60	-1.64
14	Primary metal	9.18	7.14	0.55	-0.32	0.46	1.35
15	Metal products	8.71	7.66	0.51	0.63	0.27	-0.35
16	General machinery	9.27	8.49	0.06	0.19	0.30	0.22
17	Transport machinery	10.64	9.05	0.06	-0.46	0.25	1.75
18	Electric machinery	10.05	8.64	0.14	0.26	0.23	0.78
19	Electronic & comm eqp	9.45	7.46	0.03	0.57	0.13	1.26
20	Precision equipment	2.47	1.37	-0.01	-0.55	-0.00	1.66
21	Other manufacturing	-17.33	-17.61	-0.28	-2.37	-0.31	3.24
22	Power & heat supply	5.73	1.06	3.14	-0.05	-0.06	1.65
23	Gas production & supply	12.62	4.67	6.31	0.09	0.42	1.13
24	Water supply	3.78	2.70	0.04	-0.19	0.51	0.72
25	Construction	9.27	8.75	0.19	1.48	0.16	-1.30
26	Trans & Comm	10.98	8.48	0.29	0.23	0.62	1.35
27	Commerce & restaurant	9.85	4.79	-0.01	1.43	0.76	2.88
28	Other services	11.86	7.58	0.07	0.73	1.71	1.77
Total		9.01	6.72	0.47	0.06	0.50	1.25

Source: Authors’ estimation

(2) Estimated results from 2012 to 2017

Table 6 shows the rate of increase in TFP by industry for the second half of the period. The output growth rate for all industries sharply declined to 5.8% from 9.0% in the first half. The industries with the highest rates of increase in output were transportation and communications, gas production and supply, other service industries, and construction. These are the same sectors that also showed high output growth rates in the first half of the period. This indicates that China's economy has become more service-oriented since the year 2000. In the industrial sector, the output growth rate for transportation machinery and electric machinery was large in the first half of the period; however, the growth rate of these industries slowed down in the second half of the period. Transportation and electric machinery are export industries that have previously supported the growth of the Chinese economy but their exports have declined, which is thought to be a result of the global recession.

As in the first half, the TFP growth rates in the second half of the period were generally positive, although certain industrial sectors recorded negative rates of growth. In the second half of the period, TFP rose at a higher rate in the mining industry, including coal, crude oil and natural gas, and metal mining. The main exporting industries were transportation machinery, electric machinery, and electronic and communication equipment, which decreased from 1.75% to 1.11%, 0.78% to 0.54%, and 1.26% to 0.01%, respectively. In the second half of the period, the major contribution to the increase in TFP was continued improvements in the efficiency of labor input, and the number of industries with negative labor-input effects increased over the first half of the period.

Table 6 TFP growth in China by industrial sector (2012–2017)

Unit：%

	Industry	Output	Material inputs	Energy inputs	Labor inputs	Capital inputs	TFP
1	Agric, forestry & fisheries	2.84	1.30	0.03	-2.55	-0.02	4.08
2	Coal	2.63	-0.81	0.39	-3.53	-0.14	6.73
3	Crude oil & natural gas	7.11	-2.53	-0.69	-1.36	3.77	7.92
4	Metal mining	0.83	-1.83	-0.48	-2.31	-0.15	5.60
5	Non−metallic mining	6.43	4.07	0.89	-3.08	0.85	3.71
6	Food & tobacco	6.16	5.16	0.11	-0.29	0.09	1.09
7	Fiber	0.48	0.33	0.01	-0.70	-0.07	0.92
8	Clothing & leather	3.81	4.14	0.06	-0.62	0.01	0.22
9	Wood processing & furniture	5.18	4.83	0.08	0.01	0.02	0.24
10	Papermaking & printing	4.98	4.40	0.21	-0.10	0.09	0.38
11	Petroleum & coal prods	2.99	0.46	3.06	-0.18	-0.10	-0.25
12	Chemical industry	4.75	3.09	0.38	-0.13	0.16	1.24
13	Ceramic & clay	5.64	3.86	0.87	-0.50	0.23	1.18
14	Primary metal	-0.10	-1.19	0.18	-0.54	-0.03	1.47
15	Metal products	5.47	3.77	0.28	-0.18	0.18	1.42
16	General machinery	2.00	1.36	0.04	-0.25	0.01	0.85
17	Transport machinery	5.55	4.45	0.06	-0.10	0.02	1.11
18	Electric machinery	4.07	3.14	0.05	0.19	0.14	0.54
19	Electronic & comm eqp	7.53	6.90	0.09	0.31	0.21	0.01
20	Precision equipment	7.71	6.43	0.19	-0.08	0.03	1.14
21	Other manufacturing	7.56	4.26	0.03	-1.03	0.88	3.42
22	Power & heat supply	3.36	1.21	0.65	-0.17	0.93	0.75
23	Gas production & supply	9.96	1.69	9.68	0.16	0.86	-2.43
24	Water supply	5.00	3.23	0.69	-0.79	0.40	1.47
25	Construction	7.70	7.09	0.15	0.33	0.03	0.10
26	Trans & Comm	10.22	5.34	0.31	1.54	3.34	-0.30
27	Commerce & restaurant	7.21	5.06	0.17	1.17	1.70	-0.90
28	Other services	7.60	5.54	0.13	1.48	0.07	0.39
	Total	5.78	4.04	0.28	0.05	0.42	1.00

Source: Authors' estimation

5. The TFP growth rate and CO2 emissions of the Chinese economy

The total amount of output expanded by 1.7 and 1.4 from 2007 to 2012 and 2012 to 2017, respectively. However, CO_2 emissions were 1.4 and 1.0 times higher in the first and second halves of the period, respectively. Generally, the expansion of industrial output is thought to increase energy use and CO_2 emissions. These figures indicate a decrease in CO_2 emissions per unit of production. Accordingly, this section examines the relationship between the TFP growth rate, energy productivity, and CO_2 emissions per unit of energy.

Table 7 shows the TFP growth rates (restated), energy productivity change rates, and per-unit CO_2 emissions contribution rates by industry. The shaded cells in industrial sectors indicate the top five energy-input coefficients and energy-intensive sectors; the shaded cells in TFP-increase rate and energy productivity change rate indicate the top five industrial sectors. Furthermore, the shaded cells in the CO_2 emissions per-unit contribution rate indicate the top five industrial sectors in terms of reduction rate. The shaded cells for TFP-increase rate and energy productivity change rate indicate the top five industrial sectors.

Table 7 TFP growth, energy productivity change, and CO2 emissions contribution per unit by industrial sector

Unit：%		TFP growth rate (Annual average)		Energy productivity (Annual average)		CO2 emissions contribution per unit	
		2007-12	2012-17	2007-12	2012-17	2007-12	2012-17
1	Agric, forestry & fisheries	2.88	4.08	-5.86	-0.21	-0.10	0.02
2	Coal	-0.71	6.73	-5.18	1.25	0.04	-0.13
3	Crude oil & natural gas	-1.13	7.92	5.66	19.31	0.01	-0.06
4	Metal mining	1.22	5.60	6.93	4.74	-0.02	-0.07
5	Non−metallic mining	0.41	3.71	-2.34	-0.91	0.02	-0.04
6	Food & tobacco	1.60	1.09	7.46	-1.77	-0.53	-0.70
7	Fiber	1.28	0.92	2.97	0.10	-0.17	-0.24
8	Clothing & leather	1.15	0.22	2.76	-2.82	-0.29	-0.40
9	Wood processing & furniture	1.11	0.24	5.53	2.20	-0.10	-0.27
10	Papermaking & printing	1.02	0.38	2.97	-1.25	-0.21	-0.29
11	Petroleum & coal prods	-1.40	-0.25	-1.56	-1.40	0.00	-0.06
12	Chemical industry	0.66	1.24	6.18	0.25	-0.69	-0.58
13	Ceramic & clay	-1.64	1.18	4.07	-0.98	-0.13	-0.21
14	Primary metal	1.35	1.47	3.99	-2.36	-0.27	0.01
15	Metal products	-0.35	1.42	1.37	0.74	-0.17	-0.35
16	General machinery	0.22	0.85	9.14	0.29	-0.58	-0.56
17	Transport machinery	1.75	1.11	8.80	0.37	-0.41	-0.79
18	Electric machinery	0.78	0.54	2.07	0.37	-0.54	-0.69
19	Electronic & comm eqp	1.26	0.01	9.51	-0.89	-1.05	-0.60
20	Precision equipment	1.66	1.14	3.19	-5.31	-0.04	-0.09
21	Other manufacturing	3.24	3.42	-5.20	8.23	0.13	-0.07
22	Power & heat supply	1.65	0.75	0.35	2.39	0.05	-0.06
23	Gas production & supply	1.13	-2.43	0.97	-4.77	-0.05	-0.05
24	Water supply	0.72	1.47	3.97	1.16	-0.00	-0.01
25	Construction	-1.30	0.10	-0.88	-1.48	-0.51	-0.41
26	Trans & Comm	1.35	-0.30	1.29	-1.49	-0.37	-0.54
27	Commerce & restaurant	2.88	-0.90	12.97	-2.55	-0.38	-0.43
28	Other services	1.77	0.39	11.94	-3.74	-1.28	-1.22
Total		1.25	1.00	4.53	1.92	−4.00	−5.97

Source: Authors’ estimation

(1) Energy productivity change rate

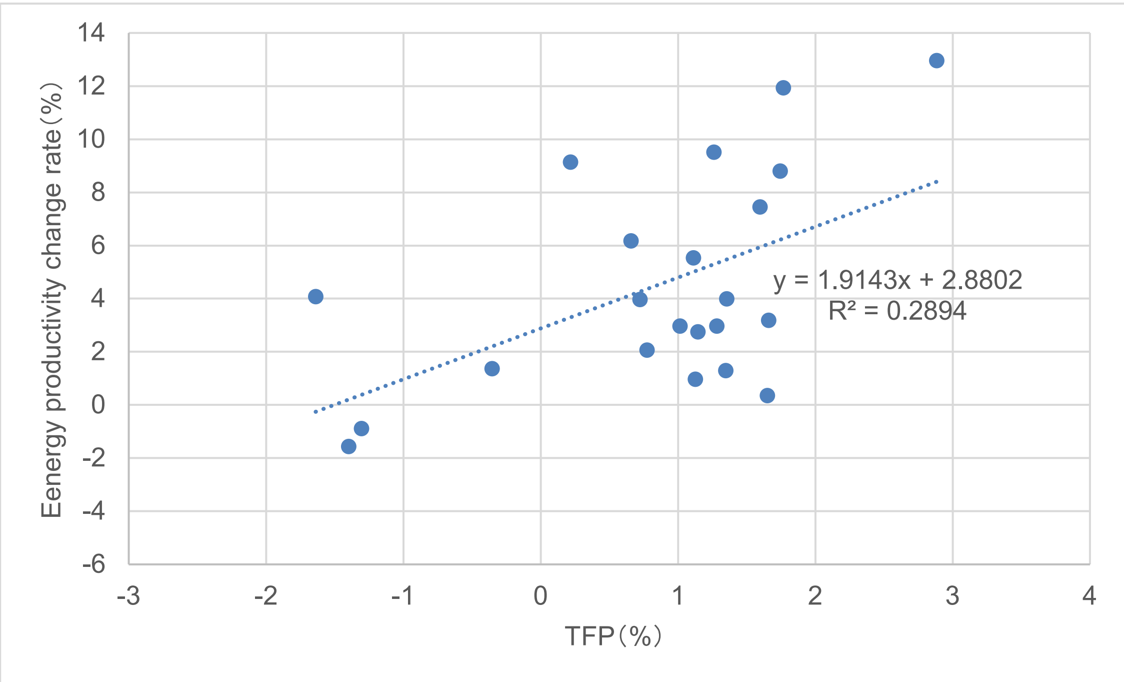
Energy productivity is "domestic production per unit of energy input." The higher the number is, the higher the energy efficiency is. The energy efficiency of all industries increased by 4.5% in the first half of the period, while improvements in efficiency declined in the second half of the period, limiting growth to 1.9%.

(2) Contribution ratio of per-unit CO_2 emissions

The contribution rate of per-unit CO_2 emissions is defined as the product of the rate of change in CO_2 emissions per unit of domestic production value versus the share of the relevant industry sector in domestic production value. The per-unit CO_2 emissions of all industries decreased by 4.0% and 6.0% in the first and second halves of the period, respectively, indicating that the impact of CO_2 emission reductions is expanding.

(3) TFP and energy productivity change rate

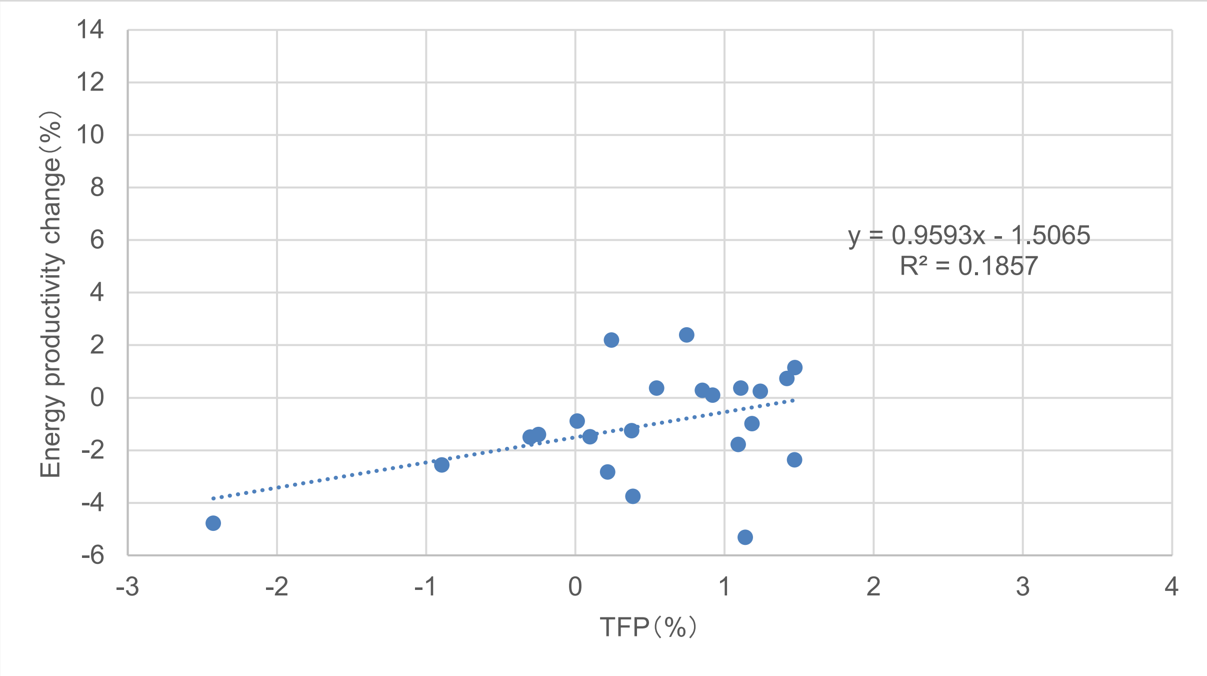
The TFP growth and energy productivity were positive in many industrial sectors in both the first and second periods, and the relationship between the two is shown in the scatter plots. Figures 2 and 3 show the relationship between the rate of increase in TFP and the rate of change in energy productivity for the first and second halves of the period, respectively[4].



Source: Authors' estimation

Figure 2 TFP and energy productivity change (2007–2012)

[4] However, other manufacturing and agriculture, forestry and fisheries were excluded.



Source: Authors' estimation

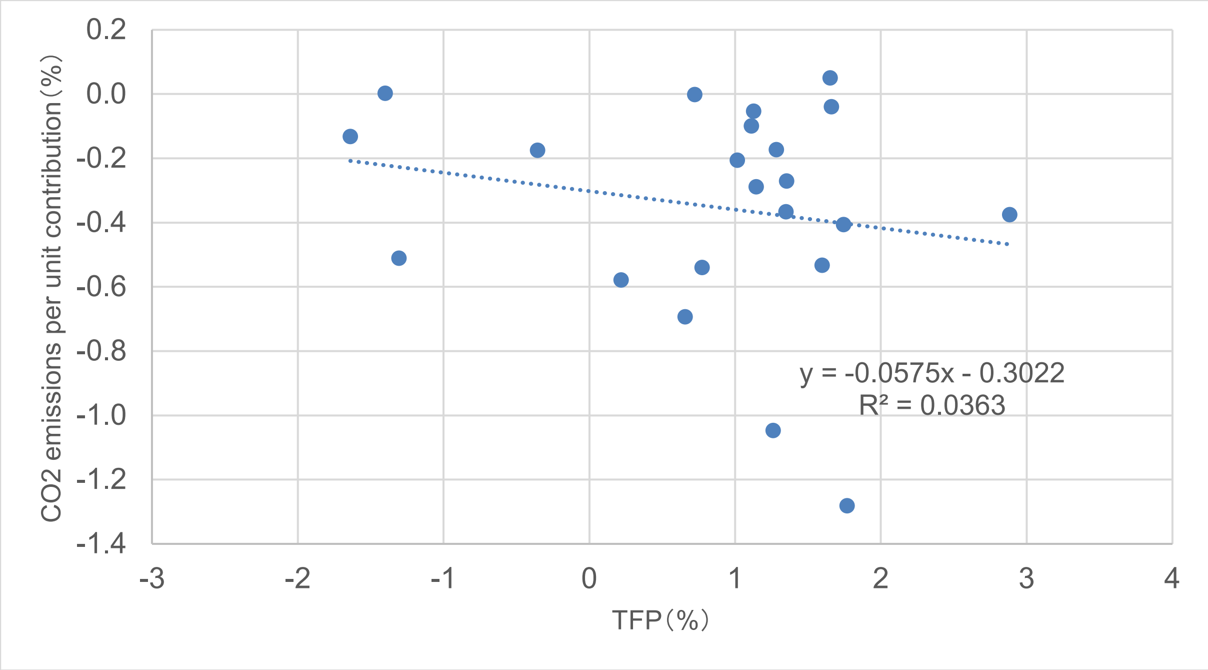
Figure 3 TFP and energy productivity change (2012–2017)

The regression lines in Figures 2 and 3 are both right ascending, indicating a positive correlation between the rate of increase in TFP and the rate of change in energy productivity. However, the correlation coefficient were 0.54 and 0.43 in the first and second halves, respectively, indicating that the correlation in the second half was not as strong as in the first half[5].

(4) TFP and CO_2 emission contribution ratio

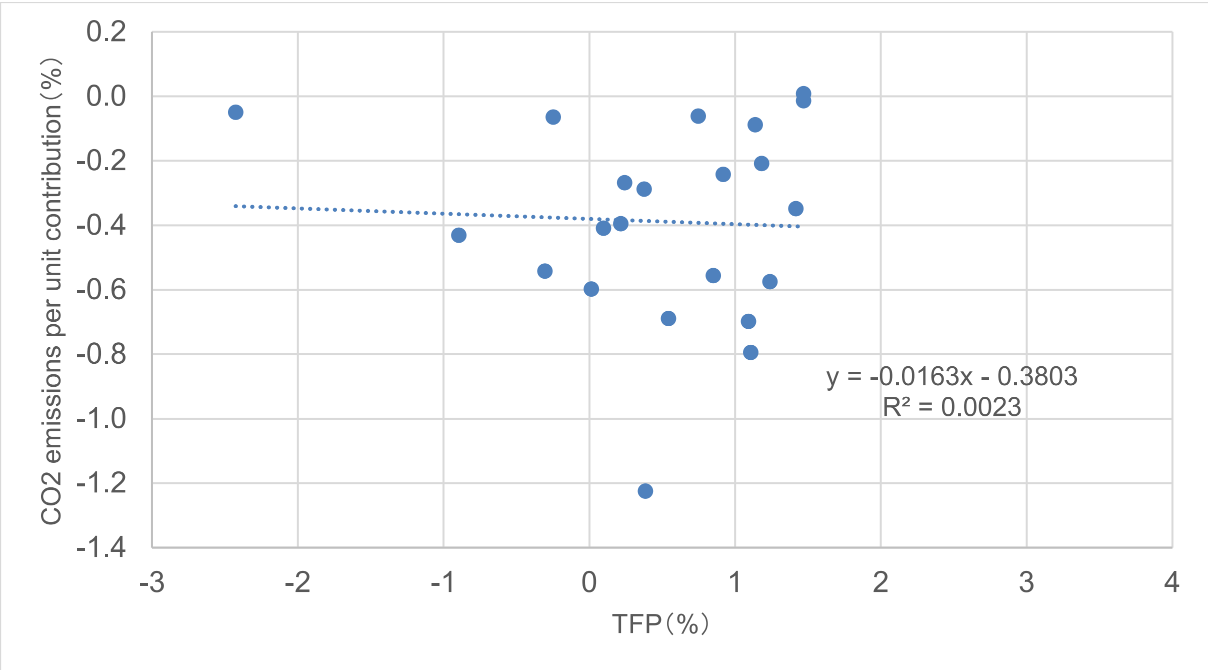
It is expected that increase in energy productivity will lower CO_2 emissions. Therefore, we examined the relationship between the rate of increase in TFP and the rate of change in CO_2 emissions. Figures 4 and 5 show the relationship between the rate of increase in TFP and the rate of contribution to CO_2 emissions in the first and second halves of the period, respectively.

[5] In Figures 2 and 3, the t-values of the slopes were estimated by the least-squares method with the explained variable as the rate of change in energy productivity and the explanatory variable as the rate of increase in TFP and the values were 2.85 in the first period and 2.13 in the second period. Both were significant at the 5% significance level.



Source: Authors' estimation

Figure 4 TFP and per-unit CO2 emissions contribution (2007–2012)



Source: Authors' estimation

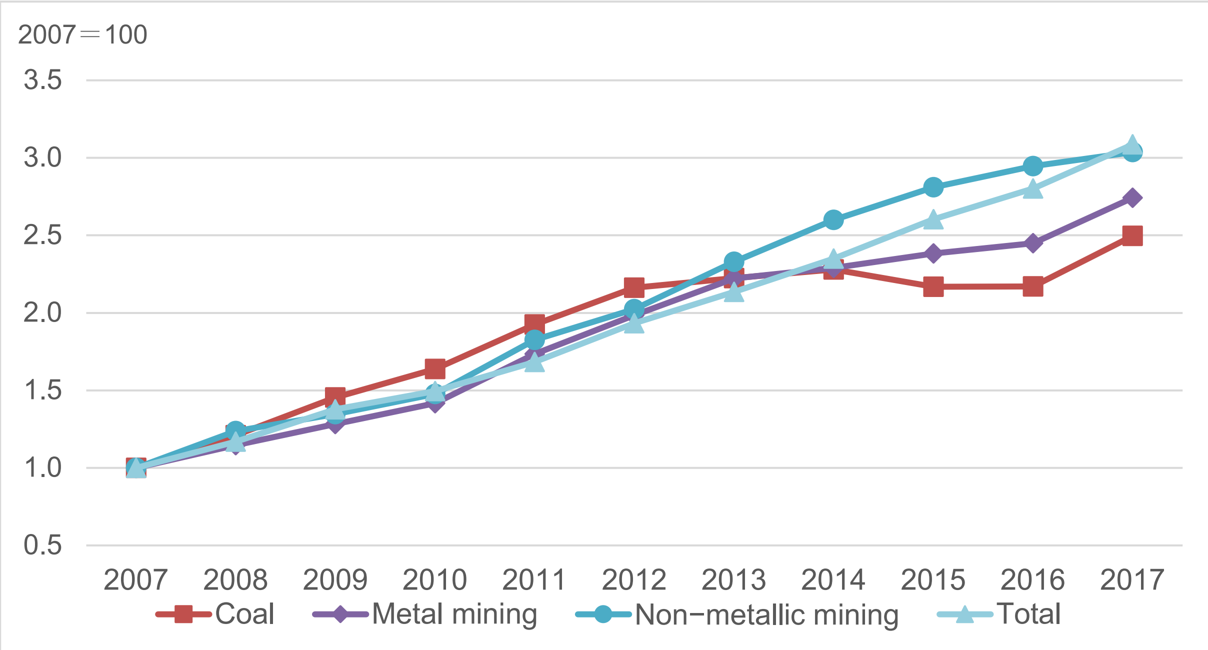
Figure 5 TFP and CO2 emissions contribution per unit (2012–2017)

In the first half of the period, Figure 4, the slope of the regression line is gradual but declines to the right, and the correlation coefficient is low at 0.19. In the second half of the period, Figure 5, the slope of the regression line is even slower than in the first half, and the correlation coefficient is extremely low at 0.05. From these results, it cannot be argued that there is a clear negative correlation between TFP and CO2 emission contribution rates[6].

6. Discussion

(1) Factors contributing to positive TFP

As discussed in Section 4, the estimated TFP growth rates were generally positive across all industries in both the first and second halves of the period. As noted above, the contribution of labor input was generally negative in both periods, with the number of negative industry sectors increasing in the second half. One possible reason for this is labor-saving technological progress against a backdrop of rising wages. Figure 6 shows the real wage index for the top three industrial sectors that reduced labor input, indicating that real wages increased about threefold over the 10-year period from 2007 to 2017.

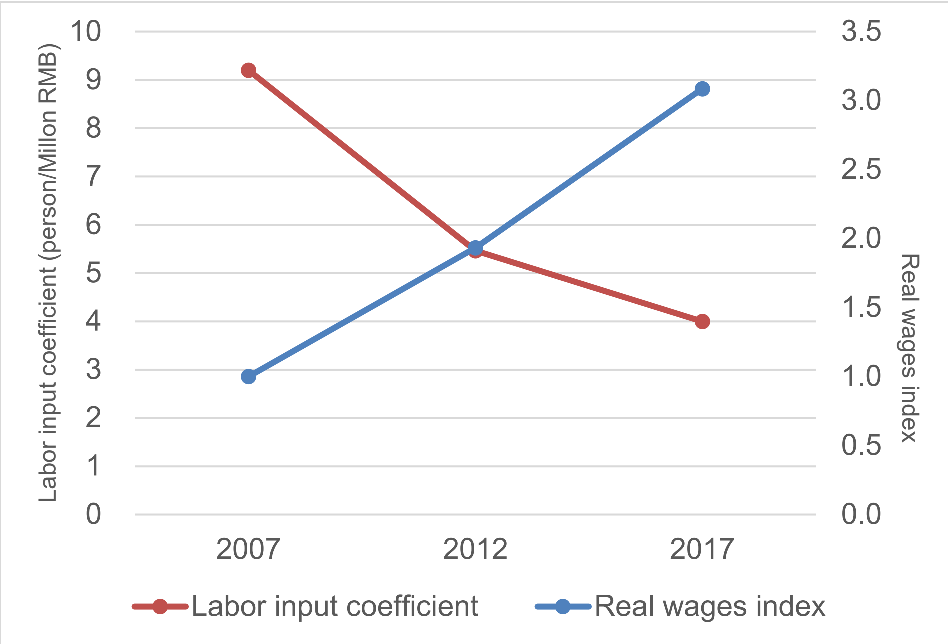


Source: Created by the authors based on China labor statistical yearbook and China statistical yearbook (each year)

Figure 6 Real wage rates in China (2007–2017)

[6] In Figures 4 and 5, the t-values of the slopes were −0.87 and −0.22 for the first and second periods, respectively, when the explained variable was the contribution rate of CO_2 emissions and the explanatory variable was the rate of increase in TFP, estimated by the least-squares method. Both were not significant at the 5% significance level. This means that the relationship between the rate of increase in TFP and the rate of contribution to CO_2 emissions cannot be argued to have a clear negative correlation.

Figure 7 shows the trends of the labor-input coefficient and real wages (in both cases, across all industries). The figure suggests that the labor-input coefficient has been declining and real wages have been increasing during the period of the analysis. Keeping in mind that the labor-input coefficient is the inverse of labor productivity, Figure 7 shows that labor productivity and real wages rose simultaneously in the Chinese economy during this period. It can be argued that firms may have responded to a rise in real wages with labor-saving technological advances during this period.



Source: Created by the authors based on China labor statistical yearbook and China statistical yearbook (each year)

Figure 7 Labor-input coefficient and real wage rate in China

(2) Factors contributing to the decline in the rate of increase in TFP

In many industrial sectors, TFP-increase rates in the second half of the period were lower than those in the preceding one. The reasons for this are discussed below. The first is a decline in production; the Chinese economy, which is highly dependent on exports, saw its output decline due to the global recession triggered by the Lehman Brothers collapse at the start of the second period. This decline in exports can be presumed to have reduced the rate of increase in production output.

The second reason is likely to be an overestimation of capital and labor input. Capital investment immediately made after the Lehman Brothers collapse resulted in an excess of capital, and the capacity utilization rate is thought to have declined. However, since the capacity utilization rate was not considered in the calculations in this paper, capital input may have been overestimated. This, in turn, may have led to the observed decline in the rate of increase in TFP. The same is true for labor input, which may also be overestimated.

(3) Relationship between TFP-increase rate and CO_2 emissions per unit

Despite improvements in energy efficiency, the relationship between the rate of increase in TFP and CO_2 emissions per unit of production was not clearly negatively correlated. We believe that this is due to the fact that only direct emissions were used as a measure of CO_2 emissions in this study. For example, if energy productivity increases in an industry but the increase is due to a reduction in electricity input and not a reduction in the input of fossil fuels, electricity consumption does not directly emit CO_2. Hence, CO_2 emissions from that industry will not be reduced using this calculation method. The CO_2 emissions data should have taken into account the indirect CO_2 emissions that are also emitted during electricity production.

7. Conclusion

In this study, we estimated the growth rate of productivity by industry for the Chinese economy over the 10-year period from 2007 to 2017. The output increased at a relatively high rate of about 9% and 6% in the first and second halves of the period, respectively, while TFP growth was positive in many individual industries in both the first and second halves. It was also generally positive across all industries over the full period. The introduction of labor-saving technologies is thought to have contributed to this increase in productivity in both halves of the period. In the latter half of the period, exports from China also declined due to the global recession following the collapse of Lehman Brothers. As a result, the production value of major export industries declined, and the rate of increase in TFP also fell from 1.75% to 1.11%, 0.78% to 0.54%, and 1.26% to 0.01% for transportation machinery, electric machinery, and electronic and communication equipment, respectively.

To clarify the relationship between productivity growth and eco-efficiency, we examined the relationship between TFP growth rate, energy productivity, and CO_2 emissions per unit of production. The rate of increase in TFP and energy productivity confirmed that, to a certain extent, productivity gains increased energy productivity. However, we could not find a clear correlation between the rate of increase in TFP and per-unit CO_2 emissions, which may be due to the fact that direct CO_2 emissions cannot be used in isolation to calculate the total amount of CO_2 emissions.

Finally, this section discusses issues for future research. First, the accuracy of the TFP estimation needs to be improved. Since the TFP growth rate in this study is defined as the difference between the rate of change in output and the rate of change in each factor of production input, the accuracy of the TFP growth rate estimation depends on the accuracy of the estimation of factors of production inputs. The capital input used in this study is based on the accounting allowance for capital depletion, which may not accurately capture the actual capital services input. The labor-input data should also be captured on a person-hour basis, taking into account the number of hours worked.

The relationship between the TFP growth rate and CO_2 emissions also needs to be estimated more precisely, and the indirect CO_2 emissions from electricity production should also be considered instead of only using direct CO_2 emissions.

References

Brandt, L., Litwack, J., Mileva, E., Wang, L., Zhang, Y., and Zhao, L. 2020. China's Productivity Slowdown and Future Growth Potential, *Policy Research Working Paper* No.9298, Word Bank.

Christensen, L., D. Cummings, and D. Jorgenson, 1980. "Economic Growth, 1947-1973: An International Comparison". In J.W. Kendrick and B. Vaccara (eds.), New Developments in Productivity Measurement, NBER Studies in Income and Wealth, 41, University of Chicago Press, Chicago, pp. 595-698.

Chenery, H., S. Shishido, and T. Watanabe, 1962. The Pattern of Japanese Growth, 1914–1954, Econometrica, Vol. 30, pp. 98-139.

Elias, V., 1990. "Sources of Growth: A survey of Seven Latin American Economies, Institute of Contemporary Studies Press.

Fujikawa, K., and Watanabe, T., 2005. Productivity growth in the Chinese economy by industry, China & World Economy, Institute of World Economics and Politics, Chinese Academy of Social Sciences, pp.56-67.

Krugman, P., 1994. The Myth of the Asia's Miracle, Foreign Affairs, Vol.73, No.6, pp. 62-78.

Saito, M., 2000. The Japanese Economy, World Scientific Publishing.

Solow, R., 1957. Technical Change and the Aggregate Production Function, Review of Economics and Statistics, Vol. 39, pp. 312-320.

Wei, S., Xie, Z., and Zhang, X. 2017. From "Made in China" to "Innovated in China": Necessity, Prospect, and Challenges, Journal of Economic Perspectives, Vol. 31, No.1,pp.49-70.

World Bank, 1993. The East Asian Miracle: Economic Growth and Public Policy, Oxford: Oxford University Press.

World Bank, 1997. China 2020, World Bank.

Wu, H., and Liang, D.2017. Accounting for the Role of Information and Communication Technology in China's Productivity Growth, RIETI Discussion Paper Series, 17-E-111, The Research Institute of Economy, Trade and Industry.

Young, A., 1994. The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growing Experience, NBER Working Paper Series No.4680, National Bureau of Economic Research. Republished in Quarterly Journal of Economics, August 1995, pp. 614-680.

Young, A., 2003. Gold into Base Metals: Productivity Growth in the People's Republic of China during the Reform Period, Journal of Political Economy, Dec, Vol. 111, pp. 1220-1261.