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The Driving Force of CO2 Reduction in China’s Industries

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ABSTRACT

We employ the joint production decomposition model to conduct a full decomposition of CO2 emission among 36 industrial sectors in China from 1998 to 2011, under the framework of growth accounting. The results show that: (1) the average CO2 emission increases at an annual rate of 3.01%, and production technology progression is the main driving force, while the transformation toward clean production effectively curb the rapid growth of CO2 emissions; (2) the effect of technology changes on CO2 emission is larger during the "10th Five-Year Plan" compared with the "11th Five-Year Plan", which makes the annual growth rate of CO2 emission during the "11th Five-Year Plan" 1% lower than its counterpart; This study has important theoretical and practical significance for understanding the driving factors of CO2 emission and the corresponding emission reduction measures.

KEYWORDS

Growth accounting; Joint production decomposition; Energy conservation and pollution reduction

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1. Introduction

Since the reform and opening up, the Chinese economy has maintained rapid growth for nearly three decades at an average annual growth rate of nearly 10%, and has achieved world-renowned achievements. However, most areas of China are still in the accelerated stage of urbanization and industrialization, and with the continuous advancement of urbanization and industrialization, China, which is entering the late stage of industrialization, has shown significant characteristics of heavy industrialization (Wang et al., 2018; Wang and Su, 2019; Lai et al., 2022). At the same time, the export-oriented economic development mode has gradually made China the "workshop of the world" (Wei and Liefner, 2012). China's global value chain participation index calculated by Koopman et al. (2014) has risen from 29% in 1995 to 40.6% in 2009. And Wang et al. (2017) also calculates that the index has shown an upward trend, especially before the world financial crisis in 2008. The co-drive of the above factors and the continuous tightening of environmental pollution and energy scarcity have severely restricted the healthy and sustainable development of China's economy (Zheng and Walsh, 2019; Liao et al., 2020). The increasing pressure of "energy conservation and emission reduction" has forced the government to seek a coordinated development path for economic growth, energy utilization and environmental protection. According to Wu et al. (2016), China's industrial sectors accounted for approximately 71% of the country's energy consumption and 85.3% of the country's GHG emissions in 2010, and the sectors produced 40.1% of the year's total GDP. Even now the industrial sectors used 66.2% of energy consumption in exchange for 38.6% of total GDP in industrial added value by NBSC's data from 2019. It can be seen that the industrial sectors are still dominated by the extensive growth mode of "high energy consumption-high emissions". Effectively improving the energy use efficiency of the industrial sectors and reducing CO2 emissions have become an important force and a key to break the dual constraints of environmental pollution and energy scarcity for China. Analyzing the driving factors behind the changes in CO2 emissions is the basic work to achieve scientific emission reduction.

Sueyoshi and Goto (2012a, 2016) summarized two ways to reduce pollution emissions in production activities: The first method reduces both good output and bad output by compressing input elements such as energy, which is simple and intuitive to operate. Therefore, it is called "natural disposability". The other method requires the introduction of new production technologies or advanced management models to achieve the goal of reducing pollution emissions. This approach is called "managerial disposability". China is currently facing an arduous task according to the "Environmental Kuznets Curve" (Dong et al., 2019; Chang et al., 2021. Although it is technically feasible to adopt natural disposability to reduce CO2 emissions, it will be at the expense of economic growth (Sueyoshi and Goto, 2012b; Wang and Wang, 2020). To achieve a win-win solution between energy conservation and emission reduction and economic growth, managerial disposability seems to be more in line with the actual needs of China at this stage (Zhang et al., 2019; Tang et al., 2020). But changes in firm production technology are closely related to the realization of managerial disposability. The analysis based on the theory of endogenous economic growth theory shows that technology changes will pass through "direct effects" and "indirect effects" to affect CO2 emissions. The direct effect is represented by "production technology change→ CO2 emission change "(Wurlod and Noailly, 2018; Xu et al., 2021; Lin and Ma, 2022). And the indirect effect is represented by "production technology change → economic growth→ CO2 emission change"(Allan et al., 2007; Hanley et al., 2009; Turner, 2009). Acemoglu et al. (2012) shows that due to the path dependence of production technology changes, firms whose initial production technology is "dirty" will have more pollution emissions due to technical progress. For firms with relatively clean initial production technology, technical progress will reduce pollution emissions. The similar conclusion from Li et al.(2021) that new technologies tend to be less environmentally friendly in the regions or industries at the low levels of innovation, and once a certain threshold is reached of the innovation level, the new technologies can reduce emissions. In addition, Chen and Lee (2020) shows that this phenomenon also exists at the national level. Technological progress in high-tech countries can reduce CO2 emissions, while this direct effect of low-tech countries is not significant, and even is positive in some groups. Du et al.(2019) explains that the high cost of diffusion of new green technologies is typically unaffordable for undeveloped regions, thus the new green technologies do not achieve the desired emission reduction effect in these regions. Based on the above reasons, the direct effect of production technology changes on CO2 emissions is uncertain, while the indirect effect of technology changes is positive.

Unfortunately, although endogenous economic growth theory analyzed the impact of production technology changes on CO2 emissions from two channels, it did not consider the impact of managerial disposability on CO2 emissions. However, it is crucial to implement differentiated emission reduction measures for different regions due to China's vast territory (Cheng et al., 2021). In addition, due to the externality of CO2 emission activities, firms aiming at profit maximization will not take the initiative to take measures to reduce emissions in the absence of external incentives. This also reflects the path-dependent characteristics of production technology changes. To this end, it is necessary to impose environmental regulatory pressure on enterprises to force firms with relatively dirty production technology to switch to clean production technology.

This paper intends to expand the existing literature: In the empirical model, we distinguish the impact of different types of production technical changes on CO2 emissions by decomposing the production technical changes into technical progress (the production frontier moves up) and technical efficiency changes (the internal points of the production possibility set move to the production frontier); This paper identifies the relative importance of natural disposability and managerial disposability in emission reduction.

The rest of this paper is organized as follows. Section 2 introduces the methodology, including theoretical models and empirical methods. Section 3 provides the description of the data. The empirical results analysis is in section 4. Section 5 summarizes the conclusions.

2. Methodology and Data

2.1. Methodology

We use the Joint Production Decomposition Model proposed by Pasurka (2006) to incorporate the pollutant emission change decomposition framework introduced in the theoretical part into the DEA model.

2.2. Data

In order to decompose the changes in pollutant emissions of China's industrial sectors, this paper finally constructed balanced panel data covering 36 industrial sectors from 1998 to 2011. This paper uses six input indicators including capital (K), labor (L) and four energy inputs, including coal (Coal), fuel (Oil), natural gas (Gas) and electricity (Electricity). A good output indicator is the total industrial output value of each industry. For bad output, this paper chooses CO2.

Table1 is the descriptive statistics of the variables. It can be seen that there are big differences between industrial sectors. Taking CO2 emissions as an example, the smallest observation value is only 750,000 tons, and the industry with the largest emissions amounts to 3.38 billion tons. In terms of output, the industry with the highest gross value of industrial output reached 10 trillion yuan, while the smallest industry was only 10.2 billion yuan.

Table 1. Descriptive statistics of input-output variables.

Var	Unit	Mean	S.D.	Min	Max
Y	Billion Yuan	773.08	1152.69	10.21	10008.25
CO_2	Million tons	158.47	434.24	0.75	3379.17

L	Thousand people	1925.60	1615.00	145.40	8194.80
K	Billion Yuan	300.90	519.98	9.77	4980.34
Coal	Thousand tons	65174.20	198122.70	199.50	1707545.00
Oil	Thousand tons	9324.20	43031.20	40.40	392448.80
Gas	Billion cubic meters	1.06	3.21	0.00	23.35
Electricity	Billion kwh	51.38	90.18	0.94	651.21

3. Empirical results

In order to examine the changes in CO2 emissions and the time trends of their decomposition items in various industries, this paper calculates the geometric average of the changes in CO2 emissions and their decomposition items for 36 industrial sectors year by year. At the same time, two important periods, namely the "10th Five-Year Plan" and the "11th Five-Year Plan" period of CO2 emissions change and the average value of decomposition items are also calculated. The results are shown in Table \ref{tab3}. As can be seen from the last row of table, the average annual increase in CO2 emissions of 36 industrial sectors during the sample period was 3.01%. The indirect effect of production technology changes has increased the average annual CO2 emissions of various industries by 5.27%, which is the most important reason for the increase in CO2 emissions. The direct effect of production technology changes has reduced the average annual CO2 emissions of various industries by 3.91%, effectively alleviating the rapid growth of industrial CO2 emissions. Even so, production technology changes still resulted in an average annual increase of 1.14% in CO2 emissions from various industries during the sample period.

Table 2. Changes and decomposition of average CO2 emissions by industrial sectors.

	EMIT	TE	TC	IG	OM	IG-NE	IG-E
2000-2001	1.0291	1.0006	1.0946	0.9787	0.9599	0.9959	0.9827
2001-2002	1.0149	1.0001	1.0588	1.0147	0.9446	0.9969	1.0178
2002-2003	1.0882	1.0002	1.1321	1.0040	0.9572	1.0009	1.0031
2003-2004	1.0299	0.9994	1.0597	1.0702	0.9087	1.0078	1.0619
2004-2005	1.0468	1.0001	1.0425	1.0364	0.9687	1.0016	1.0347
2005-2006	1.0516	1.0000	1.0306	1.0459	0.9756	1.0019	1.0439
2006-2007	1.0235	1.0000	1.0339	1.0272	0.9636	1.0031	1.0241
2007-2008	1.0193	0.9998	1.0170	1.0291	0.9742	1.0053	1.0236
2008-2009	1.0166	0.9997	1.0310	1.0049	0.9815	0.9986	1.0063
2009-2010	1.0508	1.0004	1.0437	1.0380	0.9696	1.0036	1.0343
2010-2011	0.9649	1.0002	1.0382	0.9600	0.9679	0.9955	0.9643
2000-2005	1.0415	1.0001	1.0771	1.0203	0.9476	1.0006	1.0197
2006-2010	1.0322	1.0000	1.0312	1.0289	0.9729	1.0025	1.0264
2000-2011	1.0301	1.0000	1.0525	1.0186	0.9609	1.0010	1.0175

Note: The emissions and their decomposition items in each period are obtained through the geometric average of each industry. Because some industries have infeasible solutions in different periods, this paper eliminates the observation points without feasible solutions, and then calculates the geometric average

From the perspective of specific emission reduction methods, the role of managerial disposability is very obvious, reducing the average annual CO2 emissions of various industries by 3.91%, but natural disposability has not played a corresponding role. On the contrary, the increase in the use of input factors resulted in an average annual increase of 1.94% in CO2 emissions during the sample period. It can be seen that most industrial sectors still choose the former in terms of economic development and environmental protection. It can also be seen from the decomposition items of natural disposability that the increase in energy input during the sample period leads to an increase in CO2 emissions much greater than the increase in non-energy input leads to an increase in CO2 emissions. This reflects that China's traditional "high energy consumption-high growth-high pollution" extensive economic development model has not been more fundamentally changed. At the same time, this also shows that the substitution elasticity between non-energy input factors and energy input factors is low. To achieve the purpose of energy saving and emission reduction, it is necessary to focus on improving the use efficiency of energy input.

For different periods, the average annual increase in CO2 emissions during the "10th Five-Year Plan" period was 4.15%, while the average annual increase in CO2 emissions during the "11th Five-Year Plan" period dropped to 3.22%. In the first year of the “12th Five-Year Plan”, CO2 emissions dropped by 3.51%. In terms of the indirect effects of production technology changes, the indirect effects of production technology changes during the "10th Five-Year Plan" period have increased the average annual CO2 emissions of various industries by 7.72%, which is higher than the average value of the entire sample period. The indirect effect of technological changes has increased the average annual CO2 emissions of various industries by 3.12%, and its promotion of CO2 emissions has slightly decreased. The direct effects of production technology changes during the "10th Five-Year Plan" period have reduced the average annual CO2 emissions of various industries by 5.24%, which is slightly higher than the average value of the entire sample period; The direct effect of production technology changes has reduced the average annual CO2 emissions of various industries by 2.71%, and its inhibitory effect on CO2 emissions has dropped significantly. It can be found that the indirect and direct effects of production technology changes during the "10th Five-Year Plan" period on CO2 emissions are both high, while both effects have declined during the "11th Five-Year Plan" period, which directly leads to the total effect of production technology changes. During the "10th Five-Year Plan" period, CO2 emissions increased by an average annual rate of 2.07%, while during the "11th Five-Year Plan" period, the total effect of production technology changes increased CO2 emissions by an average annual rate of 0.32%. From the perspective of specific emission reduction measures, managerial disposability played an important role in both periods, leading to an average annual decrease of 5.24% and 2.71% in CO2 emissions, respectively. The role of natural disposability in different periods is the same as that of the entire sample period. There is no big difference compared with the situation in China, which caused an average annual increase of 2.03% and 2.89% in CO2 emissions.

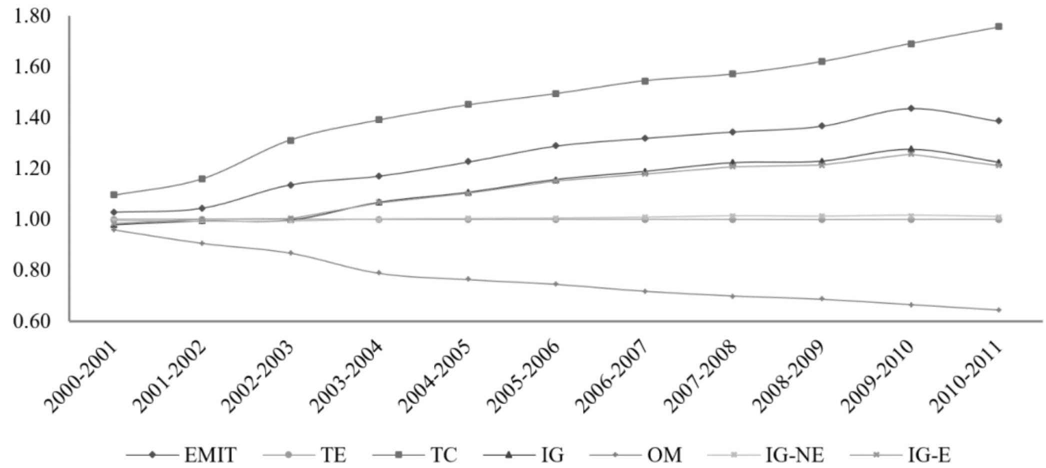

Figure 1. Cumulative changes in CO2 emissions and their decomposition items.

In order to examine the cumulative effect of changes in CO2 emissions and its decomposition items, this paper further multiplies the changes in CO2 emissions and its decomposition items with time. The results are shown in Figure 1. It can be found that the average CO2 emissions of various industries have increased by 38.56% during the sample period. Except for a slight decline in the last year of the sample period, the remaining years have maintained a relatively high growth trend. From the perspective of decomposition items, the indirect effects of production technology changes have significantly greater pulling effects on the average CO2 emissions of various industries than other factors. During the entire sample period, due to technical progress spurring economic growth, CO2 emissions increased by 75.48% cumulatively. The effect of technical efficiency changes is relatively small and has almost no impact on CO_2 emissions. The direct effects of production technology changes have reduced the average CO_2 emissions of various industries by 35.55% during the sample period, effectively restraining the rapid economic development. Simultaneous increase in CO_2 emissions. From the perspective of specific emission reduction methods, managerial disposability is the main emission reduction method during the sample period. The strengthening of environmental regulatory pressures resulted in a cumulative decrease of 35.55% in average CO_2 emissions of various industries during the sample period. The direct effect of technical progress cannot offset the increase in CO_2 emissions brought about by economic growth driven by technical progress, so overall technical progress has increased CO_2 emissions. In addition, since natural disposability will come at the expense of economic growth, they have not played a role in restraining the increase in CO_2 emissions. On the contrary, due to the increase of input factors, the CO_2 emissions increased by 22.44% cumulatively during the sample period.

4. Conclusion

We use the Joint Production Decomposition Model proposed by Pasurka (2006) by combining the Shepard distance function with joint production technology to incorporate the pollutant emission change decomposition framework introduced in the theoretical part into the DEA model, realizing the correspondence between theoretical models and empirical methods. Under the above decomposition framework, this paper comprehensively decomposes the driving factors of CO_2 emission changes in 36 industrial sectors in China from 1998 to 2011. The results show that:

(1) From an overall perspective, the average annual increase in CO_2 emissions of 36 industrial sectors during the sample period was 3.01%. The indirect effect of production technology changes is the main reason for the increase in CO_2 emissions, while the direct effect has effectively alleviated the rapid growth of industrial CO_2 emissions;

(2) From the perspective of two important periods, the average annual increase in CO_2 emissions during the 10th Five-Year Plan was 4.15%, while the increase during the 11th Five-Year Plan period dropped to 3.22%. The direct and indirect effects of production technology changes during the "10th Five-Year Plan" period on CO_2 emissions are higher than those during the "11th Five-Year Plan" period. The overall effect of the production technology changes has been reduced from an average annual increase of 2.07% in CO_2 emissions during the "10th Five-Year Plan" to an average annual increase of 0.32% in CO_2 emissions during the "11th Five-Year Plan" period. From the perspective of specific emission reduction ways, the inhibitory effect of managerial disposability on CO_2 emissions decreased significantly during the two periods, while natural disposability did not play a corresponding role in the two periods.

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Declaration of Competing Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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