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Original Research

Exploring the Spatiotemporal Coupling of Industry Development and Carbon Emissions of Energy-Intensive Industries (EII) in the Context of Industrial Transfer

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Abstract

This paper constructs a decoupling index model to explore the spatiotemporal coupling of industry transfer and emissions transfer of EII, and to obtain the factors affecting the changes of coupling by LMDI. Our conclusions are as follows: (1) there was a significant coupling of EII before 2016, but it was not clear after 2016. Specific to subindustries, they aren't synchronized with the performance of EII, the significant coupling only exists in raw chemical materials and products industry, no coupling was found in ferrous or nonferrous metal smelting and rolling industry, and in the other industries, the coupling is found only in some years. (2) For the eastern region, before 2016, the scale effect was smaller than the technological and structural effect, driving the decline in emissions; after 2016, the scale effect exceeded the others to promote the growth of emissions. For the western region, emissions growth was driven by the combined effects of scale and structure. For the central region, although the structural effect was positive before 2016, the technological effect exceeded the others to lower emissions; the structural effect turned negative after 2016, and since the structural and technological effect did not exceed the scale effect, the emissions level increased.

Keywords: industry transfer, transfer of carbon emissions, decoupling index model, LDMI method, spatiotemporal coupling

Introduction

With the deepening of globalization, the inter-regional flow of production factors has become more active since the 1990s, a new round of industrial restructuring led by developed countries has been carried out on a global scale, and large-scale industry transfer is in full swing. Industrial transfer not only promotes the optimal allocation of resources to promote the economic growth of various countries but also causes the geographical separation of commodity production and consumption, resulting in the regional transfer of carbon emissions [1, 2]. The environment is a type of global public good, and the differentiated

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environmental regulation intensity of various countries drives developed regions to make full use of such public good in the form of "free riders" such as industry transfer, to reduce their own emissions pressures by transferring emissions to less-developed regions [3]. Hence, a series of hypotheses such as "pollution haven" have emerged, explaining why backward regions become receivers of emissions from developed regions. The study of Hayashida [4], Anna et al. [5], and Bulus et al. [6] proved the existence of "pollution haven hypothesis" (PHH), they both found that in the presence of regional unilateral emissions reductions, capital flows driven by maximizing profits will promote EII transfer to developing countries with lenient environment regulations, which brings about the interregional transfer of carbon emissions, and it is believed that industry transfer will only stop when the return on capital between two countries is balanced [7]. Carbon emission shift caused by industrial transfer can be found in OECD countries, Ahmad et al [8] studied the nexus between carbon emissions and FDI based on the data of 24 OECD countries in 1993-2014, and found that FDI is one of primary sources leading to the increase of carbon emission, Balsalobre-Lorente et al [9] even saw the FDI as the culprit for the degradation of environment in PIIGs countries. As the largest developing country, China is naturally the focus of scholars when studying the relationship between international industrial transfer and carbon emission transfer [10-13], the authors studied the issue of embodied carbon based on China's international trade and FDI data, and found that FDI inflows degrade the environment quality. In addition to China, scholars also paid close attention to the countries such as GCC (Gulf Cooperation Council) countries [14], countries in the coastal Mediterranean [15], Pakistan [16], Brazil and Russia [17], Ghana [18] and the other low- and middle-income countries [19, 20]. In these studies, scholars all agree that developing countries [21], especially middle-income countries [22] are the victims of PHH, and believe that FDI increases carbon emissions in developing countries, while decreasing them in developed countries.

However, quite a few scholars have raised objections to the existence of PHH effect, believing that there is no sufficient evidence to prove the existence of PHH in China and the Philippines [23], Brazil [24], BRICS and MINT countries [25], and other emerging economies [26]. Terzi et al [27] studied the relationship between of carbon emissions and FDI inflows of Turkey in 1974-2011, and found that the PHH effect only exists in short-run. Firstly, the basic assumption of the hypothesis is that developed and developing countries have different environmental regulation policies, which result in cost-profit differences between countries, and lead to industry transfer from countries with strict regulations to countries with lenient regulations. However, industry transfer due to considerations of environmental cost does not play a significant role in the location selection of foreign investment by multinational company and even in some EII, Kim et al [28] studied the relationships of environmental regulations and FDI inflow of 120 developing countries, and found that there is a phenomenon contrary to PHH: high environmental standards significantly attract FDI, this shows that multinational companies are more inclined to seek a consistent level of environmental regulation rather than lenient environmental standards. Secondly, not all industries transferred by developed countries are polluting industries, and there are many "clean industries" among them [29], Udemba [30] found that FDI inflow to Turkey included both dirty industries and clean industries (such as agricultural practice), and there is no evidence that clean industries can also divert carbon emissions. Finally, the technology diffusion effect in industry transfer enables multinational companies to spread more advanced ecological technologies and environmental management systems to the host country [31, 32], providing motivation and opportunities for the host country to develop advanced environmental protection technology [33]; the host country can achieve less resource input and lower carbon emissions under a given output by learning, imitating advanced technology, and managing experience [34]. Behera et al. [35] examined the relationships between the FDI, green technology and emission regulation in OECD countries in 1998-2018, and found that stringent regulations on environmental protections would encourage the firms to adopt the green technology. Erdoğan et al. [36] also endorsed this viewpoint and came to the conclusion that technical progress will inhibit carbon emissions. Based on this, scholars have put forward the theory of a "pollution halo," which is the opposite of the PHH.

Although the existing literature have achieved rich results on relationship between industry transfer and carbon emissions transfer, and provides theoretical support for subsequent research, most studies have been based on trade channels to study the transfer of carbon emissions, while there are few studies based on industry transfer channels; Even in the channel of industry transfer, most are aimed at international industry transfer, so the spatiotemporal coupling effect of industrial transfer and carbon emissions transfer within a country remain to be further studied. This paper analyzes the inter-regional transfer of EII in China from 2005 to 2019 and explores whether there is spatiotemporal coupling between industrial transfer and emissions transfer, so as to provide scientific support for the green transformation and development of China's economy. A key reason for selecting EII is that they are the most important source of carbon emissions in China: their emissions account for 94.02% of China's industrial emissions and 81.75% of total emissions of production and consumption. In order to achieve the emissions reduction targets of "carbon peak" by 2030 and "carbon neutrality" by 2060, China must promote emissions reduction with EII as the driving force and the starting point. The EII studied in this paper are based on the six subindustries of EII listed in the 2021 Statistical Report on National Economic and Social Development of the People's Republic of China, including the petroleum, coal, and other fuel processing industry; the chemical raw materials and chemical products manufacturing industry; the nonmetallic mineral products industry; the ferrous metal smelting and rolling processing industry; the nonferrous metal smelting and rolling processing industry; and the electricity, heat production, and supply industry.

Materials and Methods

Division of China's Economic Regions

In order to facilitate comparative analysis on the coupling of industry transfer and carbon emissions transfer between regions, this paper divides mainland China into three parts, eastern, central, and western regions, according to administrative regions. The eastern region includes Liaoning, Hebei, Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan; the central region includes Heilongjiang, Jilin, Shanxi, Henan, Anhui, Jiangxi, Hunan, and Hubei; and the western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Yunnan, Guizhou, Shaanxi, Gansu, Tibet, Ningxia, and Xinjiang.

Sources of Data

The article selects the data of EII of 30 provinces in mainland China from 2005 to 2019 as the research sample; the data of industry development of the six major subindustries involved are from the China Industrial Statistical Yearbook (2006-2020), and the data on carbon emissions are from Carbon Emission Accounts and Datasets (CEADs, www.ceads.net.cn). Characteristics of resource endowment and ecological environment make the scale of EII in Tibet too small to be statistically significant; therefore, the following analysis does not include Tibet.

Research Methods

The existing methods to study the impact of industrial transfer on carbon emissions transfer mainly include IO-SDA and IDA, and the latter is commonly used in academia. The IDA analyzes the impact of the incremental shares of different variables on carbon emissions from the scale, structure, technology, and other aspects, which mainly includes Laspeyres index decomposition and Divisia index decomposition. The LMDI used in this paper belongs to a branch of Divisia decomposition, and is favored because of its good theoretical basis, strong applicability, easy decomposition, and no residue. By constructing the decoupling index model of carbon emissions, we use the Logarithmic Mean Divisia Index (LMDI) method to decompose the decoupling index from the level of scale, structure, and technology based on the "Kaya identity."

Building a Decoupling Index Model

Decoupling theory, which originated from physics, studies the response relationship between two variables, and was later introduced by the OECD [37] to explain the relationship between economic growth and resource consumption or environmental pollution. "Decoupling" means the blocking of the relationship between the two variables – that is, economic growth does not necessarily lead to an increase in resource consumption or environmental pollution. The OECD divides decoupling into absolute decoupling and relative decoupling: the former means that the environmental variables associated with it keep falling as the economy grows, while the latter means that the environmental variables also show an increasing trend when the economy grows, but the changes in the environmental variables are not as rapid as the economic growth. As a measure of the rupture of the coupling relationship between human activities and resource or environmental pressure, the decoupling theory has become a hot topic since it was put forward, and is used to explain the relationships between economic activities and environmental pollution [38], transportation [39], energy consumption [40], cultivated land occupation [41], etc.

Now we can obtain the decoupling indicator, reflecting the relationship between industrial development and emissions, according to the decoupling indicator model:

$$DI = \frac{\Delta CE(\%)}{\Delta MBI(\%)} = \frac{\Delta CE / CE}{\Delta MBI / MBI} \tag{1}$$

DI in the formula is the decoupling index; referring to the practice of Tapio [42], the decoupling state is divided into eight states (see Table 1). *CE* represents carbon emissions, and *ΔCE* (%) is the growth rate of carbon emissions; *MBI* represents the main business income of EII, with *ΔMBI* (%) denoting the growth rate of main business income of EII. Previous studies have mostly used the proportion of total industrial output value or industrial added value in the country to reflect changes in industrial layout. Due to the change in statistical caliber in 2011, some data were unavailable, especially the total output value or added value of specific industries, and therefore, we selected MBI as a substitute.

Using the LMDI Method to Decompose the Decoupling Index

(1) The basic principle of LMDI

Suppose that the variable *Z* is affected by *i* factors such as Z_0, Z_1, Z_2,..., and each factor Z_i is affected by *j*

Table 1. The criteria of the coupling between industry development and emissions.

Decoupling		ΔCE	ΔMBI	DI
Decoupling	Weak decoupling (WD)	ΔCE>0	ΔMBI>0	0≤DI<0.8
	Strong decoupling (SD)	ΔCE<0	ΔMBI>0	DI<0
	Recession decoupling (RD)	ΔCE<0	ΔMBI<0	DI>1.2
Linking	Growing linking (GL)	ΔCE>0	ΔMBI>0	0.8≤DI≤1.2
	Recession linking (RL)	ΔCE<0	ΔMBI<0	0.8≤DI≤1.2
Negative decoupling	Expansive negative decoupling (END)	ΔCE>0	ΔMBI>0	DI>1.2
	Strong negative decoupling (SND)	ΔCE>0	ΔMBI<0	DI<0
	Weak negative decoupling (WND)	ΔCE<0	ΔMBI<0	0≤DI<0.8

secondary indicators such as X_{10}, X_{21}, X_{22}, ..., therefore, the variable Z can be defined as: $Z = \Sigma Z_i = \Sigma X_{1j} X_{2j} ... X_{ij}$. Thus, the variable Z in period 0 and t can be expressed as: $Z^0 = \Sigma X_{1j}^0 X_{2j}^0 ... X_{ij}^0$, $Z^t = \Sigma X_{1j}^t X_{2j}^t ... X_{ij}^t$, the change rate of variable Z can be approximately decomposed into:

$$\Delta Z = Z^t - Z^0 = \Delta Z_{X1} + \Delta Z_{X2} + \cdots + \Delta Z_{Xi} \quad (2)$$

So, the influence of the k^{th} factor on the variable Z can be expressed as:

$$\Delta Z_{Xk} = \sum \frac{Z_i^t - Z_i^0}{\ln Z_i^t - \ln Z_i^0} \times \ln \frac{X_{kj}^t}{X_{kj}^0} \quad (3)$$

Equation (3) obtained by LMDI method can reflect the contribution value of each factor to the variable Z.

(2) Decompose the decoupling index by LMDI method

According to the Kaya identity, the decoupling index is decomposed from three levels of scale effect, technology effect, and structure effect.

$$CE = \sum_i CE_i = \sum_i \frac{CE_i}{MBI_i} \cdot \frac{MBI_i}{MBI} \cdot MBI \quad (4)$$

CE_i and MBI_i respectively represent the carbon emissions and main business income of the i^{th} EII subsector. The change in the scale of carbon emissions comes from three aspects: the intensity of carbon emissions ($CI_i = CE_i/MBI_i$), the structure of subindustry i in EII ($IS_i = MBI_i/MBI$), and the main business income of the EII in this area (MBI). According to the LMDI decomposition principle, the scale change of carbon emissions (ΔCE) in the "t" period relative to the base period "0" can be expressed as:

$$\Delta CE = CE_t - CE_0$$
$$= \sum_i MBI_i^t \cdot CI_i^t \cdot IS_i^t - \sum_i MBI_i^0 \cdot CI_i^0 \cdot IS_i^0$$
$$= \Delta CE_{MBI} + \Delta CE_{CI} + \Delta CE_{IS} \quad (5)$$

In the formula, CE_{MBI} is the scale effect, ΔCE_{CI} is the technical effect (carbon emissions per unit of MBI), and ΔCE_{IS} is the structural effect. Based on Equation (5), the contribution of each factor obtained by LMDI method is as follows:

The first is scale effect, reflecting the impact of industrial scale expansion on carbon emissions. Generally, the expansion of industrial scale makes a positive contribution to the growth of carbon emissions.

Scale effect (ΔCE_{MBI}):

$$\Delta CE_{MBI} = \frac{CE_{MBI}^t - CE_{MBI}^0}{\ln CE_{MBI}^t - \ln CE_{MBI}^0} \cdot \ln \frac{MBI_t}{MBI_0} \quad (6)$$

The second is technology effect, also known as the carbon intensity effect, because low-carbon technological progress will effectively reduce the emissions intensity, technological progress plays a negative role in contributing to the emissions growth.

Technical effect (ΔCE_{CI}):

$$\Delta CE_{CI} = \frac{CE_{MBI}^t - CE_{MBI}^0}{\ln CE_{MBI}^t - \ln CE_{MBI}^0} \cdot \ln \frac{CI_t}{CI_0} \quad (7)$$

The third is structure effect, reflecting the impact of industrial structure changes on emissions. Generally, the change of industrial structure has a negative contribution to the emissions growth.

Structural effect (ΔCE_{IS}):

$$\Delta CE_{IS} = \frac{CE_{MBI}^t - CE_{MBI}^0}{\ln CE_{MBI}^t - \ln CE_{MBI}^0} \cdot \ln \frac{IS_t}{IS_0} \quad (8)$$

Results and Discussion

The Spatial Pattern and Evolution of the EII

The Spatial Pattern and Evolution of the Whole EII

After entering the “Eleventh Five-Year Plan” period, the increasing pressures on resources, environment, and energy supply made EII shift from east to west. From 2005 to 2019, the proportion of EII in the eastern region had a downward trend with a decrease of 14.07%. From 2005 to 2017, the number in the other regions all showed an upward trend, but after 2017, the number in central region decreased while that in western region accelerated. On the whole, although EII have shown a trend of shifting westward, the entire industrial structure is still dominated by the eastern region. In 2019, the proportion in the eastern region in whole country was 0.562, which was about 28.27% higher than the sum of the other two regions.

Spatial Pattern and Evolution of Six Subindustries

Although there is an overall trend of shifting westward, the specific performance of each subindustry is not consistent with the whole EII. Nonmetallic mineral products industry and nonferrous metal smelting and rolling processing industry showed the most obvious trend of transferring westward. The trend of shifting westward in chemical raw material and chemical product manufacturing, ferrous metal smelting and rolling processing industry, and electricity and heat production and supply industry was already underway, but fluctuated in some years. Petroleum processing and coking industry show no signs of shifting westward, instead exhibiting a downward trend in the central region and an upward trend in the other regions.

(1) Nonmetallic mineral products industry. This industry has the largest scale of industrial transfer among subindustries. From 2005 to 2017, the proportion of MBI in the eastern region decreased from 0.683 to 0.439, a decrease of 35.72%. Although it has risen since 2017, only up 6.38%. The other regions showed a pattern of growth in 2005-2017; after 2017, differentiation began to appear, with a rapid decline in the central region and a rapid increase in the western region. The former in 2019 decreased by 18.68% compared with 2017, while the latter increased by 25.21%.

(2) Nonferrous metal smelting and rolling industry. Geological characteristics determine the industry is mostly distributed in the middle and lower reaches of the Yangtze River, which make the trend of industrial transfer from the eastern region to the central region very obvious. The proportion of MBI in the central region gradually approached that of the eastern region in 2005-2019; the difference between the two regions was only 0.004 in 2017. The proportion of MBI in the eastern region decreased from 0.486 in 2005 to 0.425 in 2019, a decrease of 12.55%; that in the central region increased from 0.282 to 0.334, an increase of 18.44%, and that in the western region showed a trend of down-up-down, with little change.

(3) Manufacturing of chemical raw materials and chemical products industry. Although the pattern dominated by the eastern region has not changed, judging by the trend of a decline in the eastern region and a rise in the other regions, the trend of industrial transfer westward has taken shape. The proportion of MBI in the eastern region decreased from 0.723 in 2005 to 0.619 in 2019, a decrease of 14.41%; that in the other regions increased from 0.160 and 0.116, respectively, to 0.227 and 0.154, an increase of 41.88% and 32.76%.

(4) Ferrous metal smelting and rolling processing industry. This is the largest energy-consuming industry, and energy pressure keeps the industry moving westward. The proportion of MBI in the eastern region showed a downward trend in 2005-2019, although there was a slight fluctuation in 2014-2016. The proportion of MBI in 2019 decreased by 10.92% compared with 2005. The industrial transfer undertaken by the western region is higher than that of the central region, so the MBI

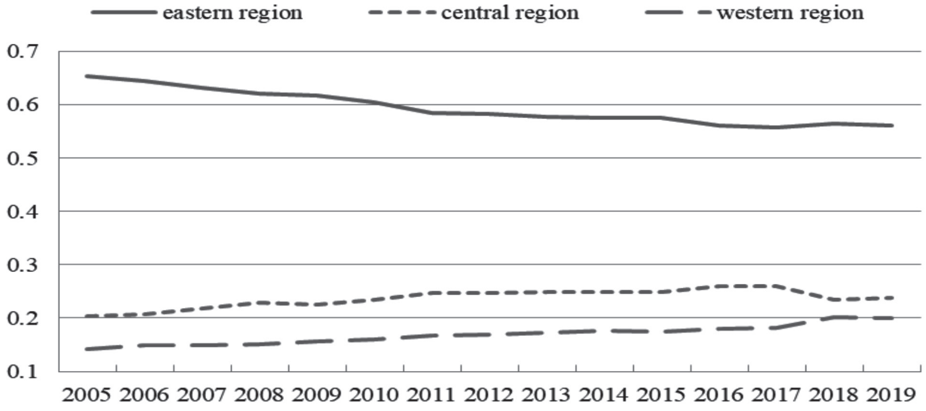

Fig. 1. The proportion of MBI of EII in the country by regions.

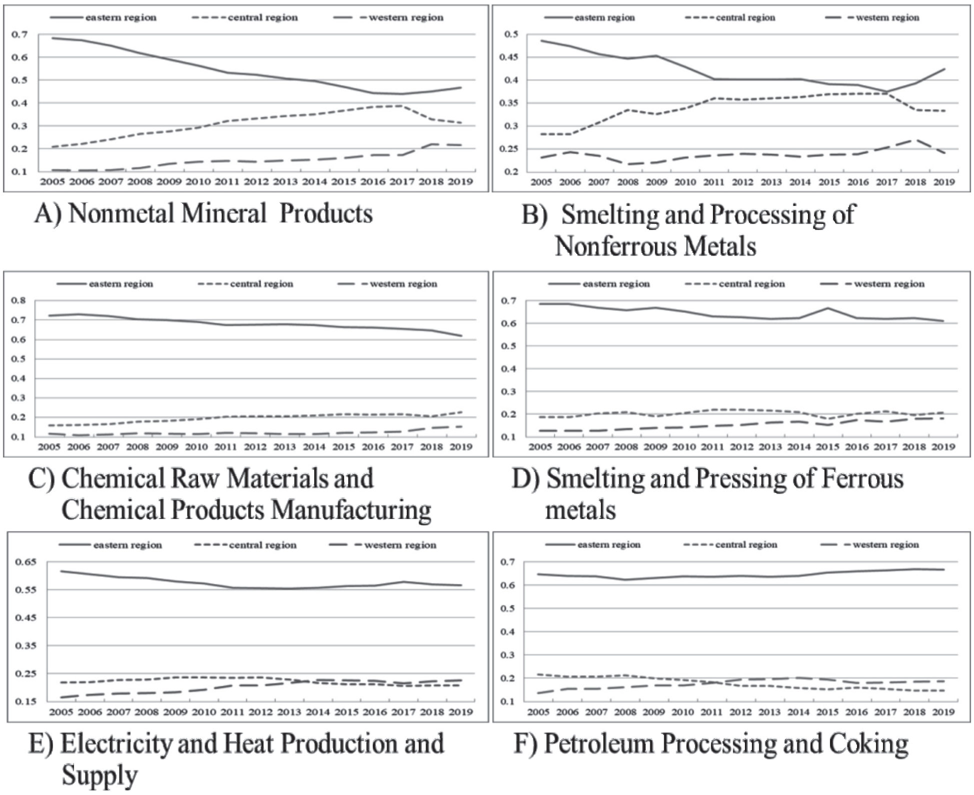

Fig. 2. The proportion of MBI of six subindustries in various regions.

of the western region increased by 42.62% compared with 2005, while the figure in the central region was only 10.78%.

(5) Electricity and heat production and supply industry. The dominance of the eastern region is the biggest feature of the industry. In 2019, the MBI in the eastern region accounted for 0.566, 30.85% higher than the sum of the other regions. The proportion of MBI in the central region showed a trend of increasing at first and then decreasing slightly – from 0.217 in 2005 to 0.208 in 2019, a decrease of 4.24%. The industrial transfer was mainly manifested in the transfer from the eastern region to the western region; the proportion of MBI in the eastern region decreased from 0.617 to 0.566, while that of the western region increased from 0.166 to 0.225.

(6) Petroleum processing and coking industry. Different from other industries, resource endowment determines the industry's transfer from the central region to the other regions. The proportion of MBI in the central region decreased from 0.216 to 0.147, a decrease of 31.94%. The other two regions increased from 0.647 and 0.137, respectively, to 0.666 and 0.187, an increase of 2.95% and 36.50%.

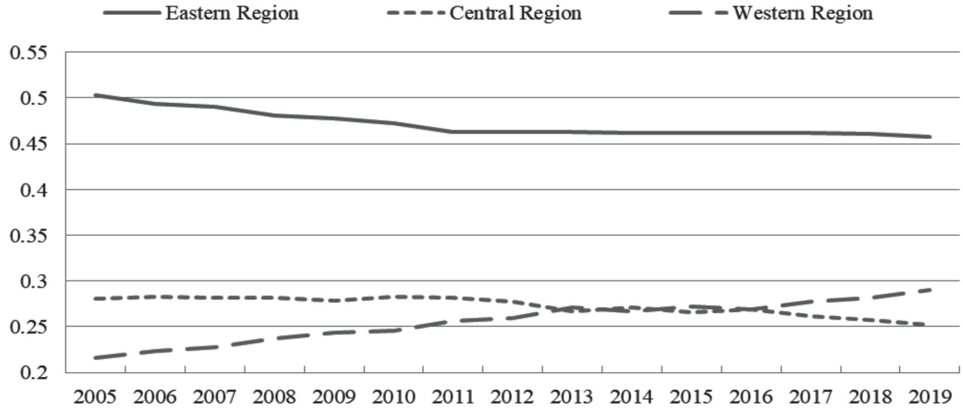

Fig. 3. The proportion of carbon emissions of EII in the three regions.

Spatial Pattern and Evolution of Carbon Emissions from the EII

Spatial Pattern and Evolution of Carbon Emissions of the Whole EII

Although emissions of EII in the eastern region continue to decrease, emissions structure is still dominated by the eastern region: in 2019, the proportion of emissions in the eastern region was 0.457, higher than the 0.252 in the central region and 0.290 in the western region. With the decline of emissions in the central region and the rise in the western region, emissions structure in this two regions has reversed: the distribution of central region >western region before 2012 evolved to even distribution in 2012-2016; the emissions of the western region have exceeded those of the central region since 2016, and the gap between the two regions has gradually widened. The proportion of emissions in the central region decreased from 0.280 in 2005 to 0.252 in 2019, a decrease of 10%, while that of the western region increased from 0.216 to 0.290, an increase of 34.26%.

Patterns and Evolution of Carbon Emissions of the Subindustries

Emissions of the subindustries in 2005-2019 are not consistent with the performance of the whole EII. Petroleum, coal and other fuel processing industries, chemical raw materials and chemical products manufacturing, and the nonmetallic mineral products industry have the most significant trends shifting from east to west. Emissions transfer of electricity and heat production and supply industry has been appearing, and this trend should not be reversed under the current environmental regulations. Emissions shifting trend of ferrous metal smelting and rolling processing industry and nonferrous metal smelting and rolling processing industry has not yet appeared (see Fig. 4 for details).

(1) Petroleum processing and coking industry. The industry's emissions showed a distribution of central region > eastern region > western region before 2012, and evolved into a distribution of central region > western region > eastern region in 2012–2017, and further evolved to a distribution of western region > eastern region > central region after 2018. The proportion of emissions in the central region decreased from 0.394 in 2005 to 0.281 in 2019, a decrease of 28.69%; that in the western region increased from 0.277 to 0.390, an increase of 40.72%; and that in the eastern region increased slightly from 0.32866 to 0.32869.

(2) Manufacturing of chemical raw materials and chemical products industry. The industry's emissions showed a distribution of eastern region > central region > western region before 2012, and evolved into a distribution of western region > central region > western region in 2012–2016, and further evolved into a distribution of western region > eastern region > central region after 2017. Overall, the proportion of emissions in the western region increased, while the number in the other regions decreased. The proportion of emissions in the eastern region increased from 0.193 in 2005 to 0.508 in 2019, an increase of 2.63-fold, that

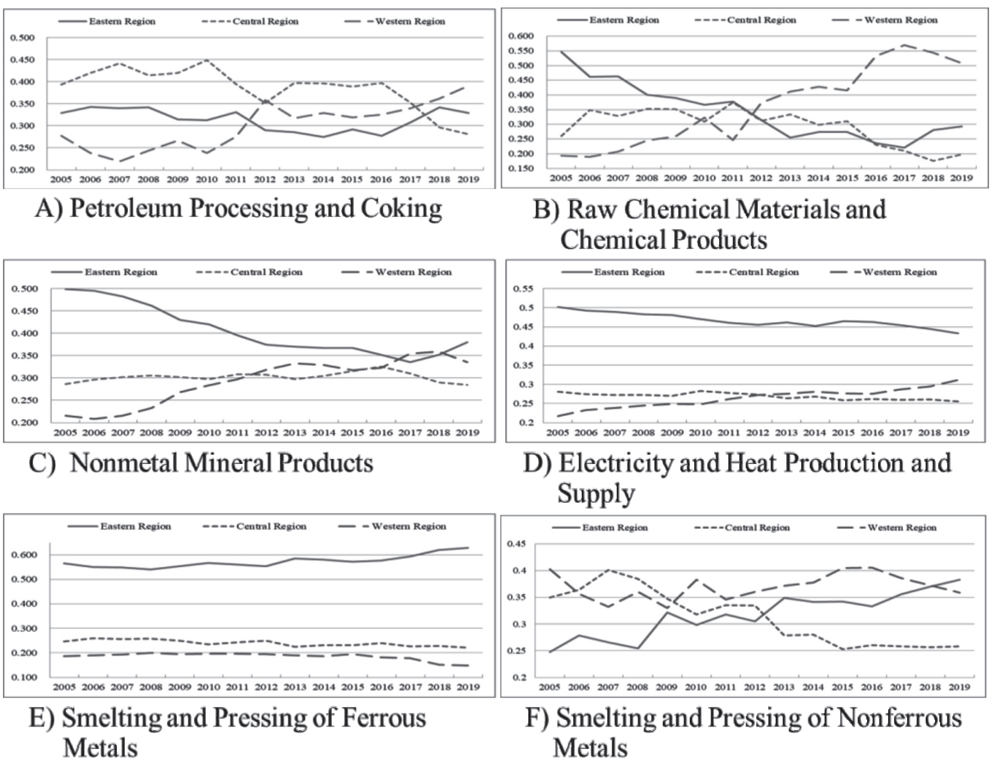

Fig. 4. The proportion of carbon emissions of six subindustries in various regions.

in the eastern region decreased from 0.547 to 0.294, a decrease of 46.33%, and that in the central region decreased from 0.260 to 0.198, a decrease of 23.73%.

(3) Nonmetallic mineral products industry. The industry's emissions showed a distribution of eastern region > central > western region in 2005–2012, and evolved into a distribution of eastern region > western region > central region in 2012–2016. Emissions in the western region surpassed those in the eastern region in 2017–2018; since then, emissions of the western region decreased and those of the eastern region increased again. Emissions trend of this industry shifting westward is very obvious. The proportion of emissions in the eastern region decreased from 0.498 in 2005 to 0.380 in 2019, a decrease of 23.83%; that of the central region decreased from 0.286 to 0.285, a slight decrease; and that of the western region increased rapidly from 0.215 to 0.335, an increase of 55.81%.

(4) Electricity and heat production and supply industry. The industry's emissions showed a distribution of eastern region > central region > western region before 2012, and then evolved into a distribution of eastern region > western region > central region. The proportion of emissions in the eastern region dropped from 0.502 in 2005 to 0.433 in 2019, a decrease of 13.75%, and that of the central region decreased from 0.280 to 0.255, a decrease of 8.93%, and that of the western region increased from 0.217 to 0.312, an increase of 43.78%.

(5) Ferrous metal smelting and rolling processing industry. The industry's emissions showed a distribution of eastern region > central region > western region, with a trend of expansion from 2005 to 2019. The proportion of emissions in the eastern region exceeded that of the other regions by 30.23% and 69.91% respectively in 2019. The proportion of emissions in the eastern region increased from 0.566 in 2005 to 0.630 in 2019, an increase of 11.31%, while that of the other regions decreased from 0.247 and 0.187, respectively, to 0.222 and 0.149, decreases of 10.12% and 20.32%. The industry's emissions showed a trend of shifting away from west to east.

(6) Nonferrous metals smelting and rolling processing industry. The industry's emissions showed a distribution of western region > central region > eastern region before 2006, and evolved into a distribution of central region > western region > eastern region in 2006-2009, western region > central region > eastern region in 2010-2012, western region > eastern region > central region in 2013-2018, and eastern region > western region > central region after 2018. The eastern region maintained a trend of volatile growth, and its proportion of emissions increased from 0.247 in 2005 to 0.383 in 2019, an increase of 54.81%. The central region maintained a trend of volatile decrease, and its emissions proportion in the country is 0.350 in 2005, and 0.258 in 2019, a decrease of 26.29%, and that of the western region showed a slight downward trend, from 0.403 to 0.359.

The Spatiotemporal Coupling of EII Transfer and Emissions Transfer

Spatiotemporal Coupling of Whole EII Transfer and Emissions Transfer

According to the changes in growth rate of MBI and emissions of EII in each region, we divided the research period of 2005-2019 into three stages: 2005-2012, 2012-2016, and 2016-2019, and used a decoupling index model to describe the relationship between industrial development and carbon emissions, to obtain the coupling law between industrial transfer and emissions transfer, and to analyze the factors affecting the coupling by using the LMDI method.

The relationship between industrial development and emissions in the eastern region was in recession linking before 2012, at this time for every 1% dropped in EII scale, emissions decreased by 1.01%. However, the relationship shifted to weak negative decoupling after 2012, meaning that with the decline in the scale of EII, emissions have continued to decline. For the central region, the relationship changed from weak decoupling to strong decoupling by 2016 – at this time, with the expansion of the industrial scale, emissions changed from a slight increase to a slight decrease. The relationship turned into strong negative decoupling after 2016, at this time with the decline in the industrial scale, emissions increased slightly. Taking 2012 as the dividing line, the relationship in the western region has changed from growing linking to weak decoupling, and with the expansion of the industry, emissions have changed from rapid growth to slow growth. From the above analysis, it can be seen that, before 2016, the coupling between emissions transfer and industrial transfer of EII was relatively significant, but it became less clear after 2016.

For the eastern region, the sum of technology and structural effect was higher than scale effect before 2016, which driving carbon emissions down; after 2017, the scale effect exceeded the sum of the technology and structure effect, which caused an increase in emissions. For the central region, the structural effect was positive due to undertake industrial transfer from the eastern region before 2016, but emissions showed a downward trend because the technological effect exceeded the sum of the other effects, after 2016, the structural effect turned negative due to outward transfer of the EII: for the scale effect was smaller than the other effects, emissions continued to decline. The western region is the main carrier of EII, so the structural effect is positive, and the combination of scale and structure effect increases carbon emissions.

The Coupling between Industry Transfer and Emissions Transfer of Six Subindustries

(1) Petroleum processing and coking industry. According to the changes of growth rate of MBI and

Table 2. The coupling between EII and carbon emissions in various regions.

Regions		ΔCE	ΔMBI	Decoupling index		Scale effect (%)	Technical effect (%)	Structural effect (%)	Carbon emissions
				Index	Type				
2005-2012	ER	–0.102	–0.101	1.010	RL	1065	–1351	–37	Decreasing
	CR	0.063	0.218	0.289	WD	921	–959	31	Decreasing
	WR	0.181	0.177	1.023	GL	1302	–870	117	Increasing
2012-2016	ER	–0.008	–0.060	0.133	WND	61	–24	–42	Decreasing
	CR	–0.034	0.052	-0.654	SD	104	–156	45	Decreasing
	WR	0.041	0.072	0.569	WD	140	–112	24	Increasing
2016-2019	ER	–0.005	–0.063	0.079	WND	84	–23	–34	Increasing
	CR	0.002	–0.069	–0.029	SND	197	–47	–163	Decreasing
	WR	0.014	0.102	0.137	WD	68	–83	164	Increasing

Note: In the table, ER is used to represent the eastern region, CR is used to represent the central region, and WR is used to replace the western region.

emissions in each region, the research period was divided into three stages: 2005-2012, 2012-2017, and 2017-2019. Taking 2012 as the dividing line, the relationship between industrial development and emissions in the eastern region has changed from recession decoupling to expansive negative decoupling in 2005-2017. Before 2012, as the industrial scale declined, emissions decreased at a faster rate. After 2012, with the industrial scale starting to rise, emissions likewise started to rise rapidly. Before 2017, the relationship in the central region was in negative decoupling, with the decline in the scale, emissions also decreased; after 2017, however, the western region entered into recession decoupling, with the decline in industrial scale, emissions continued to decrease. The relationship in the western region was in weak decoupling in 2005-2012: as the industrial scale expanded, emissions rose slightly. After 2012, it turned into linking: it was in growing linking in 2012-2017, emissions continued to increase with the expansion of the industrial scale; after 2017 it turned to recession linking, emissions also decreased with the decline in industrial scale. Before 2012, the industrial scale and emissions all showed a trend of declining in the central and eastern regions, and increasing in the western region, indicating that the coupling was clear. After 2012, the industrial scale showed a trend of declining in the central region, and increasing in the other regions, while emissions showed a trend of changing slightly in the central region, increasing in the eastern region, and increasing at first and then decreasing in the western region, so the coupling between industrial transfer and emissions transfer was not very clear.

(2) Chemical raw materials and chemical products manufacturing industry. To this industry, the research period was divided into two stages: 2005-2011, and 2011-2019. From 2005 to 2019, the relationship between industrial development and emissions in the eastern region was in recession decoupling, while that in the western region was in expansive negative decoupling, meaning that emissions in the eastern region were decreasing at a faster rate, while those in the western region were increasing by a faster rate. The relationship in the central region changed from expansive negative decoupling to strong decoupling, with emissions showing a trend of increasing at first, and then decreasing. Therefore, the coupling between industrial transfer and emissions transfer in this industry was clear.

(3) Nonmetallic mineral products industry. To this industry, the research period was divided into two stages: 2005-2018, and 2018-2019. Before 2018, the relationship between industrial development and emissions in the eastern region was in recession linking, as the decline in industrial scale led to a rapid decrease in emissions; after 2018, the relationship entered a state of expansive negative decoupling, and emissions have risen at a faster rate with the expansion of the industrial scale. The relationship in the other regions was in weak decoupling from 2005 to 2018, at this time emissions continued to increase. However, differentiation began to occur in 2018: the central region entered a state of weak negative decoupling while the western region was in recession decoupling, meaning that emissions decreased with the decline in the industrial scale – the former at a low speed and the latter at a high speed. Before 2018, the proportion of this industry decreased in the eastern region and increased in the other regions, emissions also showed a trend of decreasing in the eastern region and increasing in the other regions at this time, so the coupling between industrial transfer and emissions transfer was clear. After 2018, the industry still showed a trend of decreasing in the eastern region and increasing in the other regions, but emissions all showed a downward trend, so the coupling was not obvious.

Table 3. The coupling between industry development and emissions of subindustries.

Six subindustries		Eastern region		Central region		Western region	
		Index	Type	Index	Type	Index	Type
Petroleum processing and coking industry	2005-2012	9.075	RD	0.474	WND	0.708	WD
	2012-2017	1.749	END	–0.004	SND	0.863	RL
	2017-2019	12.027	END	3.590	RD	5.332	GL
Chemical raw materials and chemical products manufacturing industry	2005-2011	4.625	RD	1.648	END	6.243	END
	2011-2019	2.703	RD	–4.044	SD	3.984	END
Nonmetal mineral products industry	2005-2018	0.863	RL	0.022	WD	0.631	WD
	2018-2019	1.996	END	0.393	WND	4.249	RD
Ferrous metals smelting and rolling processing industry	2005-2015	–0.500	SND	2.057	RD	0.238	WD
	2015-2019	–1.166	SND	–0.283	SD	–1.209	SD
Non-ferrous metals smelting and rolling processing industry	2005-2008	–0.357	SND	0.537	WD	1.711	RD
	2008-2017	–2.469	SND	–3.086	SD	0.423	WD
	2017-2019	0.586	WD	0.002	WND	1.484	RD
Electricity and heat production and supply industry	2005-2012	0.947	RL	–0.316	SD	0.993	GL
	2012-2019	–2.561	SD	0.551	WND	1.719	END

(4) Ferrous metals smelting and rolling processing industry. To this industry, the research period was divided into two stages: 2005-2015, and 2015-2019. The relationship between the industrial development and emissions in the eastern region was in strong negative decoupling in 2005-2019, meaning that emissions continued to increase with the industrial scale decline. The relationship in the central region was in recession decoupling, while that in the western region was in weak decoupling before 2015, meaning that emissions in the central region decreased with the industrial scale decline in the central region, while emissions in the western region increased at a lower speed with the industrial scale expansion. However, after 2015, both regions turned into strong decoupling, thus, as the industrial scale expanded, emissions decreased. Therefore, the coupling between industrial transfer and emissions transfer in this industry was not obvious.

(5) Non-ferrous metals smelting and rolling processing industry. To this industry, the research period is divided into three stages: 2005-2008, 2008-2017 and 2017-2019. The relationship between the industrial development and emissions in the eastern region was in strong negative decoupling before 2017, meaning that although the industrial scale declined, emissions still showed an increasing trend; after 2017, the relationship evolved into weak decoupling: with the industrial scale growth, emissions also showed an increasing trend, although its growth is in a lower speed. The relationship in the central region evolved from weak decoupling to strong decoupling in 2005-2017, meaning that with the industrial scale expansion, emissions went from slightly increasing to decreasing; after 2017, the relationship turned to weak negative decoupling, as the industrial scale continued to decline, and emissions decreased as well. The relationship in the western region showed a trend of recession decoupling–weak decoupling–recession decoupling. On the whole, the relationship of emissions and industrial development do not show a coupling relationship shifting from east to west.

(6) Electricity and heat production and supply industry. To this industry, the research period was divided into two stages: 2005-2012, and 2012-2019. Taking 2012 as the dividing point, the relationship between the industrial development and emissions in the eastern region evolved from recession linking to strong decoupling, that in the central region changed from strong decoupling to weak negative decoupling, and that in the western region developed from growing linking to expansive negative decoupling. For the eastern region, the decline in the industrial scale led to a downward trend in emissions before 2012, and emissions kept going down after 2012, although the industrial scale expanded. For the central region, emissions showed a downward trend with the industrial scale expansion before 2012, and emissions kept going down after 2012 while the industrial scale decreased. For the western region, as the industrial scale expanded, emissions kept growing and the growth rate is accelerated. Before 2012, the spatial pattern of the industry showed the trend of decreasing in the eastern region and increasing in the other regions, while the spatial pattern of emissions showed a trend of increasing in the western region and decreasing in the other regions, the coupling between industrial transfer and emissions transfer in this industry was clear. After

2012, the spatial pattern of the industry showed a trend of decreasing in the central region and increasing in the other regions, the spatial pattern of emissions showed a trend of increasing in the western region and decreasing in the other regions, so the coupling relationship after 2012 is unclear.

Conclusions

Based on the data of EII from 30 provinces in 2005–2019 in mainland China, this paper discusses the nexus of industrial transfer and emissions transfer. First, we constructed a decoupling index model to find the spatiotemporal coupling laws of industrial transfer and carbon emissions transfer. Then, we used the LMDI method to decompose the decoupling index from three levels of scale, structure, and technology, and explored the influencing factors of this coupling relationship.

(1) Huge pressures on resources, environment, and energy supply meant that the EII of developed areas show a trend of transferring westward. However, the performance of each subindustry is not consistent with the whole EII. Among them, nonmetallic mineral products and the smelting and rolling of nonferrous metals have the most significant trend of shifting westward; the transfer trend of smelting and rolling of ferrous metals and electricity and heat production and supply has been formed, but is not stable; the transfer trend of petroleum processing and coking has not appeared.

(2) The total emissions increased year by year in 2005-2019, but the growth rate was high in the western region and low in the eastern region, and the EII showed a significant transfer trend from east to west. However, emissions trend of each subindustry is not in sync with the whole EII: petroleum processing and coking, chemical raw materials and chemical products manufacturing, and nonmetallic mineral products had the most significant emissions shift trends; emissions transfer of electricity and heat production and supply has formed but was not significant. Emissions transfer trend of smelting and rolling of ferrous and nonferrous metals has not yet appeared.

(3) According to the decoupling index model, the industrial scale and carbon emissions all showed a trend of declining in the eastern region and increasing in other regions before 2016, meaning that there was a significant coupling relationship between industrial transfer and emissions transfer. However, after 2016, the industrial scale showed a distribution of growth in the western region and decline in the other regions, and emissions showed a trend of decreasing in the eastern region and slight growth in the other regions, therefore, the coupling relationship was not clear. Using the LMDI method to decompose the coupling index, we found that the dominant factors causing coupling index change are different in different regions and different periods. For the eastern region, the scale effect is smaller than the sum of the other effects before 2016, leading emissions to decrease; however, after 2017, the scale effect exceeded the sum of the other effects, causing emissions to increase. For the central region, the structural effect was positive due to undertaking the industrial transfer before 2016, but the technological effect exceeded the sum of the other effects, driving emissions downward; after 2017, although the structural effect was negative, under the combined effect of structural and technological effects, emissions continued to decrease. As the main undertaker of EII, the western region showed positive structural effects in 2005-2019, under the combination of scale and structural effect, emissions maintained long-term growth. We found that the coupling between industrial transfer and emissions transfer of each subindustry was not the same: the coupling in chemical raw material and chemical product manufacturing is the most significant; petroleum processing and coking and electricity, heat production and supply showed coupling in 2005-2012, and non-metallic mineral products in 2005-2018, while coupling in the smelting and rolling processing of ferrous and nonferrous metals was not clear.

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Conflict of Interest

The authors declare no conflict of interest.

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