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EFFECTS OF CHINA'S REGIONAL INDUSTRIAL STRUCTURE ADJUSTMENT ON CARBON EMISSION TRANSFER BASED ON GRAVITY MODEL

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Abstract

In China, there exist major differences in both the energy consumption and industrial structure between provinces and cities, leading to carbon emission transfer. Based on inter-provincial trade and industrial transfer, this paper measures the carbon emission transfer of China's sub-sectors and cities in 2007 and 2010 using the inter-provincial input-output model. The results show that, carbon dioxide transfers from economically developed regions and regions with a single industrial structure to economically underdeveloped regions or resource-intensive regions. The embodied carbon emission transfer mainly occurs between provinces and cities in the eastern, central and northeastern regions of China. A gravity model with a direction vector is constructed to analyse the influence of the regional industrial structure distance, environmental regulation distance, technical distance and geographical distance on carbon emission transfer. The results show that: there is a spatial proximity effect in carbon emission transfer; technical distance and industrial structure distance promote carbon emission transfer from economically developed regions to economically underdeveloped regions; the primary industry structure distance has a significant positive impact on the outflow of carbon emissions; The secondary industry structure distance and the carbon emission outflow show an "inverted U-shaped" relationship, while the tertiary industry structure distance and the carbon emission outflow show a "U-shaped" relationship; The carbon emission transfers from regions with strict environmental regulations to regions with loose regulations, thus verifying the existence of the "pollution haven hypothesis". This conclusion provides a reference for rationally dividing the responsibility for carbon emission reduction across various regions.

Key words: carbon emission transfer, distance, gravity model, regional industrial structure

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1. Introduction

There are large gaps in terms of factor endowment, main function, industrial layout, and economic development level among various regions in China. The regional economic gradient provides an intrinsic motivation for domestic industrial transfer. At the same time, in the process of industrial structure optimization and adjustment in various regions of China, developed regions tend to transfer some high-energy-consumption and high-polluting industries to underdeveloped regions with low environmental standards, resulting in carbon emission transfer across China's regions. Therefore, in addition to accounting for the direct emission of carbon dioxide from various regions, it is equally important to calculate the emissions that are locally generated in order to meet the consumption and production needs of other regions, that is, the trade embodied carbon emissions transfer.

That is to say, on the basis of considering regional industrial transfer, the current study analyses the carbon emissions transfer effect of regional industrial structure adjustment, aiming to provide a solid theoretical basis for the fair and objective division of regional ecological climate responsibility,

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and the promotion of coordinated and sustainable development of China's regional economy.

2. Literature review

Representing the spatial displacement of industry, industrial transfer mainly occur via trade and technology transfer among different countries or regions. The issue of "carbon emissions transfer" and "carbon leakage" caused by industrial transfer and international trade adjustment has begun to attract academic attention (Anvar et al., 2018; Lin and Sun, 2010). Early scholars mainly used Merge, GREEN, GTAP-E and other models to simulate carbon emission transfer in various regions. The results show that inter-regional carbon emission transfer are common in existing scenarios (Babiker, 2005; Kuik and Gerlagh, 2003; Li, 2000; Manne and Richels, 2000). Considering the limitations of the above models, since the input-output model can simultaneously integrate industries and regions into a unified system, the latter method has gradually been applied to the carbon dioxide emission potential assessment process of industrial restructuring (Hetherington, 1996; Ma et al., 2017; Munksgaard and Pederson, 2001; Rhee and Chung, 2006). Furthermore, Fu et al. (2018) presented a Dorfman-Samuelson-Solow model, using an energy-carbon emission/economic multiregional input-output table of China reflecting embodied carbon within products and services among the country's various regions as an entire system. Lenzen et al. (2004) set up a five-region input–output model including Denmark, Germany, Sweden and Norway in order to calculate CO2 multipliers and trade balances. Using the input and output-life cycle assessment method, Lu and Li (2015) calculated the implied carbon emissions transfer between Chinese provinces.

Another aspect to consider here is that, due to the differences in natural resources, technology, equipment and energy use efficiency, there is a large carbon emissions transfer from developed countries to China. Some scholars have used the input-output model to measure the amount of carbon emissions transferred from China, the United States and other developed countries, and the results show that the value is about 7%-23% (Li and Hewitt, 2008; Shui, 2006; Yu and Wang, 2010; Wang and Chang, 2018). McKibbin (1999) found that most carbon emission transfer occur between countries with emission reduction targets, rather than from countries with emission reduction targets to non-emitting countries. Peters and Hertwich (2008) argue that international trade promotes the free transfer of carbon emissions and carbon leakage, whereby developing countries are generally the net importers of trade-embodied carbon emission transfer, while developed countries are net exporters. Ma and Wang (2015) used the multi-regional input-output model (MRIO) to measure the trade-embodied carbon emissions among China, the United States and Japan from 2000 to 2011. The results show that China is in the net exports of embodied carbon emissions, with the scale effect being the main driving force for the growth of China's export-embodied carbon emissions. Han et al. (2018) also applied multi-regional input-output (MRIO) analysis to identify embodied carbon flows between major world regions, including seven regions along the Belt and Road (BR), and the spatial distribution of production- and consumption-based carbon intensities. The results show that current embodied carbon flows virtually all go from BR regions to developed countries, with more than 95% of world net embodied carbon exports coming from BR regions. Consumption in the United States and European Union countries induce about 30% of the carbon emissions in most BR regions, indicating that the former bear a high proportion of consumer responsibility for the carbon emitted in the latter.

In the context of the development of a low-carbon economy, industrial transfer have provided a route for energy conservation and emissions reduction; that is, a reasonable carbon emissions transfer among industries is not only a basis for the transformation and upgrading of industry, but is also the foundation for achieving industrial carbon emissions reduction targets (Sun et al., 2018). Taking the Pan-Yangtze River Delta area at the stage of industrial transfer as a case study, Li and Cao (2013) analyzed the relationship between carbon emission patterns and regional industrial transfer, finding that changes in the industrial output value, product structure and carbon emission intensity caused by industrial transfer in various regions are closely related to changes in carbon emission patterns; they also found industrial transfer to be an important factor affecting changes in regional carbon emission patterns.

China's regional development varies widely, as the industrial structure and dependence on energy in different regions are very different. There are also large spatial differences in terms of structural emissions reductions and policies on emissions reductions. During the critical period of the transfer of coastal industries to the central and western regions of China, regional industrial restructuring was a key factor leading to carbon emission transfer (Liu et al., 2010). Shi et al. (2012) used the regional input-output model to measure carbon emissions transfer, finding that carbon emissions in China have undergone a spatial transfer from energy-rich regions and heavy chemical bases to economically developed regions and underdeveloped regions with incomplete industrial structures. Sun et al. (2014) calculated the total amount of carbon emissions transferred into and out of China's inter-provincial regions based on the input-output model. The results show the total amounts of carbon inflows in each region to be greater than the total amount of carbon emissions.

Carbon emission transfer show certain spatial cluster characteristics. Regions with more developed economies in the eastern and central areas of China show high-high cluster models, while those in the western and underdeveloped regions in the central areas show low-low cluster models. Guo et al. (2012) analyzed the characteristics of China’s CO_2 emissions embodied in interprovincial trade at province level, using the multi-regional input–output model, finding that the net transfer of embodied CO_2 emissions flowed from the eastern area to the central area, and that energy-intensive industries were the main contributors. Cheng et al. (2017) applied EEBT and a two-stage SDA model to analyze the characteristics and driving force of the spatial-temporal evolution of net carbon emissions embodied in interprovincial trade (CEs-PT) outflow in the Northeast Industrial District of China (NID). Cheng et al. (2017) also found that, during 1997–2007, the net CEs-PT flowed out from the NID first to 16 southern and eastern provinces, and then to 23 provinces all over China, with the main driving forces being technology and demand. For their part, Cheng and Wei (2013) argue that industrial transfer will lead to an increase in carbon emissions in the transfer zone, that the energy intensity effect of the industry's net transfer zone will continue to shrink, and that an economic structure effect will appear. With reference to the 1997 China Inter-regional Input-Output Table, Yao and Liu (2010) used the EIO-LCA method to analyze the transfer pattern of China's eight major interregional products (services) trade-embodied carbon emissions, finding that the north coastal and central areas undertook the transfer of high-carbon load industries in other regions, and were net importers of embodied carbon emissions. Deng and Yang (2018) calculated 2002-2012 CO_2 emissions transfer in embedded carbon emissions in China's eight major regions using the interregional input-output method and obtained the same results.

Xiao et al. (2014) and Liao and Xiao (2017) examined the effects of the “carbon emission shift” and “carbon leakage” brought about by regional industrial transfer. These authors found that the northwest and northeast regions have become the hardest hit areas in terms of carbon emissions and carbon leakage through the transfer of the eastern coastal industries; at the same time, Beijing-Tianjin and the northern coastal areas manifested the carbon emissions reduction effect of industrial transfer. Pan (2017) found that the carbon leakage faced by China mainly lies with inter-regional trade, rather than foreign trade. The net emission of carbon emissions from Guangdong, Jiangsu, Zhejiang and other regions represent the transfer of carbon emissions from abroad to domestic transit, while Shanxi, Inner Mongolia and Hebei are subject to the net inflow of carbon emissions and are the destinations for carbon emissions. Scholars agree that coastal industrial transfer or regional trade has led to the aggravation of pollution in China’s central and western regions. The reason for this is that the coastal areas mainly transfer high-carbon, energy-intensive, resource-based industries and related manufacturing.

Through a detailed review of the relevant literature, existing researches have studied the measurement and characteristics of carbon emission transfer from the perspectives of industrial transfer and inter-national trade, and mainly adopt the multi-region input-output model. To date, the main studies have focused on carbon transfer in inter-national trade, and there are few studies on carbon transfer due to inter-regional trade within countries. Moreover, most of the carbon emission transfer areas in the existing literature are divided according to the “eight major regions” of the input-output table. However, this is not an appropriate approach by which to study the carbon transfer problem. For example, Sichuan, Chongqing, Yunnan, Guizhou and Guangxi are divided into southwestern regions by the input-output table. Some studies that have been designed in accordance with the “eight major regions” indicate that the southwest region is where carbon emissions are transferred into, and that it is based on this that the carbon quotas in the southwest region are allocated; in fact, different provinces and cities in the southwest region have significantly different carbon emission transfer characteristics. Therefore, using countries and large regions to analyze input-output makes it difficult to match the unique structures of industries, trade and technology in various provinces, and makes it impossible to formulate policies with strong pertinence and operability. It is, therefore, necessary to measure the scale of carbon emission transfer on a provincial scale and analyze the spatial characteristics of inter-provincial carbon emission transfer.

In the body of research on the factors affecting carbon emissions and carbon emission transfer, the literature has confirmed that industrial structure, economic scale, technical level, environmental regulation and other factors are the key aspects affecting carbon emissions, using structural decomposition or regression methods. The existing research has, essentially, clarified the types of driving force and contribution rate of inter-regional carbon transfer. However, it has also been found that the driving force changes dynamically during the evolution of a carbon transfer. It is thus important to analyze the impact of the interaction of driving forces on the spatial pattern of carbon transfer, as this is of great significance to revealing the mechanism of carbon emission transfer in a scientific manner.

Given China’s vast territory, there is a big gap between the provinces in terms of resource endowment, economic level, energy consumption structure and industrial structure, resulting in significant differences in the pattern and status of the inter-provincial division of labor. At the same time, inter-provincial trade has caused the geographical separation of the production and consumption of some commodities, which has led to the serious problem of inter-provincial carbon emissions transfer. Given the driving role of product consumption in trade embodied carbon emissions, consumers of products and services are responsible for the carbon emissions generated during the production of these products and services. An unfair assumption of the responsibility for carbon emissions will limit the balanced development of the regions and reduce the overall efficiency of China's development of a low-carbon economy. Therefore, it is necessary to analyze the impact of key factors, such as industrial structure differences between provinces and cities, on the transfer of carbon emissions. Furthermore, clarifying the responsibility for carbon emissions after considering carbon emission transfer is another key issue that should be paid attention to when formulating carbon emission reduction policies.

Above all, using the Chinese inter-provincial input-output table, and based on the analysis of the measurement and spatial characteristics of embodied carbon emission transfer between provinces and cities in China, this paper draws on the gravitational model (commonly used in national trade issues) to explore the impact of regional industrial structure distance, environmental regulation distance, technology distance and other factors on carbon emission transfer. At the same time, in order to remain aligned with the flow of carbon emissions, distance factors, such as the regional industrial structure distance proposed in this paper, are directional. That is, the paper considers not only the degree of regional industrial structure differences, but also the degree of optimization or backwardness of industrial structure in a certain region relative to other regions. By analyzing the impact of regional industrial structure distance on carbon emission transfer, this paper aims to provide a reference for objectively understanding the carbon emission responsibility of each province and city, and then for rationally allocating carbon emission reduction responsibilities. Due to the difficulty of obtaining inter-provincial input-output data, the current empirical analysis could reflect the impact of inter-provincial industrial structure differences on the spatial characteristics of carbon transfer, but it could not describe the dynamic evolution process and law of inter-provincial carbon emission transfer. In the future, we will obtain more and updated inter-provincial input-output data, combine this with the structural decomposition method, analyze the dynamic driving mechanism of carbon emission transfer, and allocate carbon emission quotas based on the principle of fairness and development.

3. Carbon emission transfers across provinces

3.1. Carbon emission transfer measurement across provinces

In the economic system, carbon emissions are implicit in the commodity exchange chain and are diverted via commodity exchanges. The number and type of commodity flows between regions determine the structure and direction of carbon emissions. With the current state of economic globalization and the development of domestic market integration, the trade between different regions is gradually expanding. In addition to meeting local needs, the products of a certain region can also be used as intermediate products in other regions. The inter-regional input-output model uses commodity and labor flows to link the regional input-output models so as to form a cross-regional input-output model that reflects the economic linkages between industries within a region. This, therefore, makes it feasible to use the input-output model to measure inter-regional commodity flows and then calculate inter-regional carbon emissions.

China's inter-regional input-output table is based on the competitive input-output model. Its premise is that both imported and domestic products are homogeneous and fully competitive. While the trade transfer can roughly be estimated in the case of relatively few imported products, as the market becomes more open the trade between countries worldwide grows more frequent, and China's imports are coming to occupy a large share of consumer goods. Su and Ang (2013) measured the difference between embodied carbon emissions by comparing competitive and non-competitive input-output models, finding that the results of the competitive model were significantly higher than those of the non-competitive model. The non-competitive input-output model separates imports from intermediate products and final demand. Its premise is that imported products and domestic products perform differently and cannot be seen as interchangeable and can accurately reflect trade flows between regions. The basic structure of the non-competitive input-output tables in various provinces and regions is shown in Table 1. The non-competitive input-output model considers that intermediate input products imported from other regions enter the production process, but do not pollute the regional ecological environment, thus separating imports from intermediate products and final needs, which can more reflect inter-regional trade flows, and can avoid overestimating the scale of implied inter-regional carbon emissions from trade. The current paper employed the non-competitive input-output data of the six major industrial sectors of 30 provinces and cities in China in 2007 and 2010 (Hong Kong, Taiwan, Macao and Tibet are missing due to lack of data). The basic structure of the simplified, non-competitive input-output table for these provinces and cities is shown in Table 1. For the purposes of this paper, it is supposed that a country's national economy is divided into *n* regions. This article refers to 30 provinces and cities of China, each region containing six industrial sectors ($\boldsymbol{i = 1, 2, \cdots, 6}$ represents farming, forest, livestock, and fishery products; construction; industry; transport and storage; wholesale and retail; other service industries). In Table 1, $\boldsymbol{F_i^{RS}}$ represents the final demand of region *S* for products of sector *i* in region *R*. $\boldsymbol{A_{ij}^{RS}}$ represents the intermediate demand of the sector *j* in region *S* for products of sector *i* in region *R*. $\boldsymbol{X_j^S}$ represents the total investment of sector *j* in region *S*. $\boldsymbol{E_i^R}$ indicates the export of sector *i* in region *R*. $\boldsymbol{IM_j^S}$ indicates the intermediate consumption of imported products by sector *j* in region *S*. $\boldsymbol{V_j^S}$ represents the added value of the sector *j* in region *S*. $\boldsymbol{X_i^R}$ represents the total output of sector *i* in region *R*.

Table 1. Basic structure of non-competitive input-output model

<table>
<tr><td colspan="3" rowspan="3">input-output</td><td colspan="7">Intermediate demand</td><td colspan="6">Final demand</td><td rowspan="2">Total output</td></tr>
<tr><td colspan="3">Province 1</td><td>⋮</td><td colspan="3">Province n</td><td colspan="2">Province 1</td><td>⋮</td><td colspan="2">Province n</td><td>Export goods</td></tr>
<tr><td>sector 1</td><td>……</td><td>sector 6</td><td>……</td><td>sector 1</td><td>……</td><td>sector 6</td><td>expenditures</td><td>Total capital</td><td>……</td><td>expenditures</td><td>Total capital</td><td></td><td></td></tr>
<tr><td rowspan="7">Intermediate input</td><td rowspan="3">Province 1</td><td>sector 1</td><td colspan="7" rowspan="7">$\boldsymbol{A_{ij}^{RS} X_j^S}$</td><td colspan="5" rowspan="7">$\boldsymbol{F_i^{RS}}$</td><td rowspan="7">$\boldsymbol{E_i^R}$</td><td rowspan="7">$\boldsymbol{X_i^R}$</td></tr>
<tr><td>⋮ ⋮</td></tr>
<tr><td>sector 6</td></tr>
<tr><td>⋮ ⋮</td><td>⋮ ⋮</td></tr>
<tr><td rowspan="3">Province n</td><td>sector 1</td></tr>
<tr><td>⋮ ⋮</td></tr>
<tr><td>sector 6</td></tr>
<tr><td colspan="3">Imported goods</td><td colspan="7">$\boldsymbol{IM_j^S}$</td><td colspan="5">$\boldsymbol{FM^S}$</td><td colspan="2"></td></tr>
<tr><td colspan="3">Value Added</td><td colspan="7">$\boldsymbol{V_j^S}$</td><td colspan="7" rowspan="2"></td></tr>
<tr><td colspan="3">Total investment</td><td colspan="7">$\boldsymbol{X_j^S}$</td></tr>
</table>

In the inter-regional non-competitive input-output model, the line-to-balance matrix is expressed as follows (Eq. 1):

$$X^R = A^{RS} X^R + F^{RS} + E^R \quad (1)$$

Where X^R denotes the total output column vector for each sector of region *R*, and $A^{RS}(R \neq S)$ is the inter-regional direct consumption coefficient matrix, reflecting the intermediate demand of each sector in region *S* for each sector in region *R*. F^{RS} denotes the final demand of each sector in region *S* for region *R*, and E^R is export vector of region *R*.

Eq. 1 is transformed to obtain (Eq. 2):

$$X^R = \sum_{\substack{S \neq R \\ S=1}}^{n} A^{RS} X^S + A^{RR} X^R + \sum_{\substack{S \neq R \\ S=1}}^{n} F^{RS} + F^{RR} + E^R \quad (2)$$

Where: $\boldsymbol{A^{RR}}$ is the direct consumption coefficient matrix in region *R*.

According to Eq. (2), (Eq. 3) is then obtained:

$$X^R = (I - A^{RR})^{-1}\left(\sum_{\substack{S \neq R \\ S=1}}^{n} A^{RS} X^S + \sum_{\substack{S \neq R \\ S=1}}^{n} F^{RS} + F^{RR} + E^R\right) \quad (3)$$

Eq. (3) shows that the total output of region *R* consists of four parts.

Where: $(I - A^{RR})^{-1} \sum_{\substack{S \neq R \\ S=1}}^{n} F^{RS}$ represents the portion of the total output of region *R* that is used for the final demand in other regions; $(I - A^{RR})^{-1} \sum_{\substack{S \neq R \\ S=1}}^{n} A^{RS} X^S$ represents the portion of the total output of region *R* that is used for intermediate inputs in other regions; $(I - A^{RR})^{-1} F^{RR}$ represents the portion of the total output of region *R* that is ultimately for its own demand, and $(I - A^{RR})^{-1} E^R$ represents the portion of the total output of region *R* used for export. Therefore, from the perspective of demand, the carbon emission transfer from region S to R comes from two sources. Firstly, the carbon emission transfer from region S to region R through the flow of final demand. Secondly, the carbon emission transfer from region S to region R through the flow of intermediate products. That is, the transfer of carbon emission from region S to region R means that region R bears the responsibility for carbon emission reductions belonging to region S, whereby the amount of carbon emission transfer from region S to region R can be expressed by Eq. (4):

$$T^{RS} = D^R (I - A^{RR})^{-1} (A^{RS} X^S + F^{RS}) \quad (4)$$

where: D^R represents the row vector composed of the direct carbon emission coefficient of each industrial sector in region R, where the i-th element $D_i^R = \frac{C_i^R}{X_i^R}$ denotes the total carbon emissions of the i-th industrial sector in region R divided by the total output of the i-th industrial sector.

Similarly, the carbon emission outflow caused by trade from region R to region S can be expressed as follows (Eq. 5):

$$T^{SR} = D^S (I - A^{SS})^{-1} (A^{SR} X^R + F^{SR}) \quad (5)$$

According to $T^R = \sum_{S=1}^{n} T^{SR}$, the total amount of carbon emission outflow of region R can be obtained. Applying $T^R = \sum_{S=1}^{n} T^{RS}$ yields the total amount of carbon emissions inflow of region R. Carbon emission outflow minus carbon emission inflow gives the net outflow of carbon emission.

Carbon emissions are mainly derived from the burning of various fossil fuels. According to the IPCC Guidelines for National Greenhouse Gas Inventories (2006) and the Guidelines for the Preparation of Provincial Greenhouse Gas Inventories, the carbon dioxide emission factor for the p-th fossil energy is calculated by Eq. (6):

$$EF_p = NCV_p \times CEF_p \times COF_p \times (44/12) \quad (6)$$

where: EF_p represents the carbon dioxide emission factor of the p-th fossil energy source, NCV_p represents the average low calorific value of the p-th fossil energy, CEF_p represents the unit calorific value carbon content of the p-th fossil energy source, and COF_p represents the carbon oxidation rate of the p-th fossil energy source. For the purposes of this paper. The carbon emission factor of each fossil energy sources is calculated using Eq. (6) (as shown in Table 2).

Finally, the CO_2 emissions of provincial terminal energy consumption could be calculated, as follows (Eq. 7):

$$C = \sum_p FC_p \cdot EF_p \cdot K_p \quad (7)$$

where: C indicates carbon dioxide emissions, FC_p indicates the consumption of p-th fossil energy, and K indicates the energy terminal commitment ratio, set to 1.

This paper use the input-output tables of the six major industrial sectors (farming, forest, livestock, and fishery products; construction; Industry; transport and storage; wholesale and retail; other service industries) in 30 provinces and cities in China in 2007 and 2010, and the energy balance table of each provinces to calculate the amount of embodied carbon emissions between provinces and cities in 2007 and 2010.

Since the six major industrial sectors in the inter-provincial input-output table in 2007 and 2010 correspond exactly to the industries in the energy consumption balance table, it was possible to calculate the fossil energy consumption of each province and city by directly calculating the terminal energy consumption of the industry according to the energy balance Table.

Table 2. Carbon dioxide emission factors of various fossil energy sources

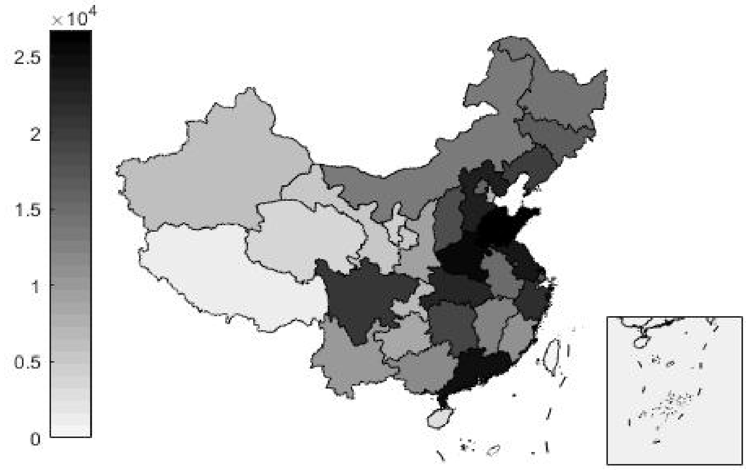
Energy classification	***Average low calorific value（kJ/kg, m³）***	***Unit calorific value carbon content（kgC/GJ）***	***Carbon oxidation rate (%)***	***Carbon emission factor***
Raw coal	20908	26.4	94	1.90
Washed coal	26344	25.4	93	2.28
Other coal washing	10441	25.4	93	0.90
Briquette	17563	33.6	90	1.95
Coke	28435	29.5	93	2.86
Coke oven gas	17333	12.1	99	0.76
Other gas	20197	12.1	99	0.89
Other coking products	38053	29.5	93	3.83
Crude	41816	20.1	98	3.02
Gasoline	43070	18.9	98	2.93
Kerosene	43070	19.6	98	3.03
Diesel	42652	20.2	98	3.10
Fuel oil	41816	21.1	98	3.17
Liquefied petroleum gas	50179	17.2	98	3.10
Refinery dry gas	45998	18.2	98	3.01
Other petroleum products	35125	20	98	2.52
Natural gas	38931	15.3	99	2.16

Data Source: *IPCC Guidelines for National Greenhouse Gas Emission Inventory in 2006*

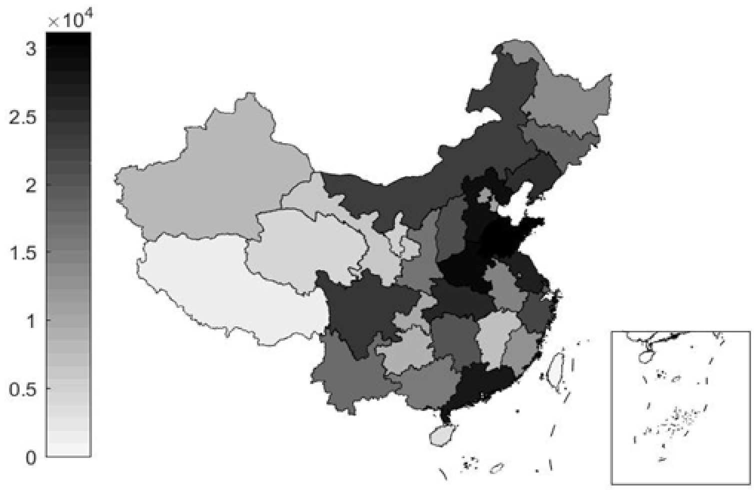
The carbon emissions of the provinces and cities were then obtained according to the various energy carbon emission factors provided by the IPCC, and the direct carbon emissions coefficient yielded by dividing by the total output of each industry. It should be noted that although electricity and heat account for a large proportion of emissions during production processes, it is generally believed that the carbon dioxide produced by the production side has already been measured and, in order to avoid double counting, it is regarded as a zero emission in the terminal consumption process. Therefore, we did not calculate the carbon dioxide produced by the electricity and terminal heat consumption in the energy balance table. The spatial distribution of total carbon dioxide emission is show in Fig. 1.

It was found that the spatial distribution of carbon footprint was uneven, with more in the eastern and northern China and less in the western and southern China. Shandong, Hebei, Shanxi, Henan and Inner Mongolia are rich in coal and other fossil resources. The industrial structure is dominated by heavy industry, and energy efficiency is low, so the total carbon footprint is large; the large-scale economic of Guangdong and Jiangsu leads to large carbon emissions. However, due to the shortage of coal and other fossil energy resources, Guangdong and Jiangsu mainly develops light industry, and have transferred the industries with high pollution and high energy consumption to other regions.

The net carbon emission transfers from China's provinces and cities in 2007 and 2010 are obtained using Eqs. (4) -(7) and the related data, as shown in Fig. 2. Here, it can be seen that provinces with a positive net outflow of embodied carbon emissions can be divided into two categories: first, economically developed provinces with a high per capita GDP, such as Guangdong, Shanghai and Jiangsu; second, provinces with a single industrial structure and limited level of economic development, such as Heilongjiang, Jiangxi and Hainan. The provinces with a net inflow of embodied carbon emissions are mainly divided into two categories: first, economically underdeveloped provinces, such as Gansu, Qinghai and Ningxia; second, provinces with rich natural resources, such as Hebei, Inner Mongolia and Shanxi.

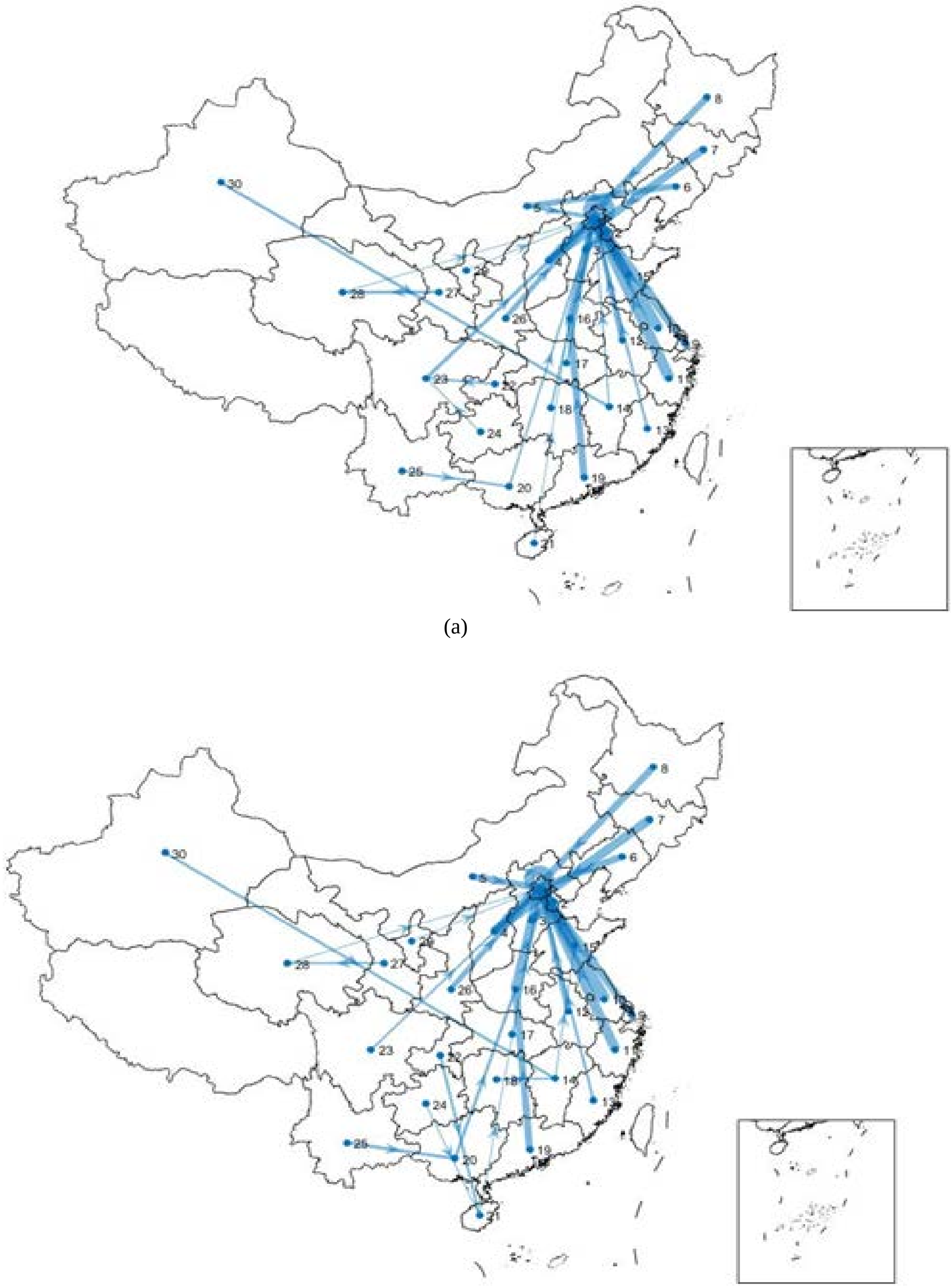


(a)



(b)

Fig. 1. Spatial distribution of carbon emissions in China: (a) Spatial distribution of carbon emissions in China in 2007 and (b) Spatial distribution of carbon emissions in China in 2010



(a)

(b)

Fig. 2. Schematic diagram of carbon emissions transfer in 2010 and 2007: (a) Schematic diagram of carbon emissions transfer between provinces and cities in 2007 and (b) Schematic diagram of carbon emissions transfer between provinces and cities in 2010

The transfer trend of embodied carbon emissions between regions mainly flows from economically developed and industrial structure-imperfect regions in eastern and central China to economically underdeveloped and resource-intensive regions in western China.

From the perspective of the regional structure of carbon transfer, economically developed regions that have the advantages of industrial structure and economic output often transfer energy-intensive, highly polluting industries to economically less developed regions, meaning that economically underdeveloped regions tend to become "pollution havens". In addition, regions with a single industrial structure, especially those dominated by agriculture and services, can only transfer the industrial products or services of other provinces and cities by provincial trade in order to meet the demand of local production or consumption, meaning that the carbon belonging to the area is transferred to other areas. Regions with a single industrial structure become trade embodied carbon emission net exporters. The carbon emission intensity of resource-intensive provinces and cities is often high. Given that resource-intensive provinces supply energy demands such as coal, electricity and related primary products to other provinces and cities with a poorer industrial structure, this leads to carbon dioxide transfer from other regions to resource-intensive regions through the regional spillover effect or an industry-related effect.

At the same time, there is a clear spatial proximity with carbon emission transfer, with the embodied carbon emission transfer mainly occurring between provinces and cities in the eastern, northeastern and central regions of China. Specifically, the embodied carbon emissions of Beijing flow into Hebei, Shandong, Inner Mongolia and other provinces and cities. The embodied carbon emissions of Hebei mainly flow into Shanxi, Henan, Shandong and other provinces and cities. The embodied carbon emissions of Jiangsu mainly flow towards Hebei, Anhui, Henan and other provinces and cities. The embodied carbon emissions of Guangdong mainly flow into Guangxi, Yunnan, Hunan, Guizhou and other provinces and cities. This shows that in the process of regional economic integration, although provinces and cities carry out a division of labor and cooperation with surrounding provinces and cities due to geographical reasons, giving full play to their comparative advantages, they also bring about carbon emission transfers. In order to reduce the negative impact of regional trade on the responsibility for emission reductions, it is necessary to promote regional cooperation in these reduction efforts, formulate a distribution scheme of cooperative emission reduction revenue, and realize the reciprocal sharing of energy conservation and emission reduction technologies within each region.

3.2. Spatial correlation analysis of regional carbon emission transfer

In order to further judge the spatial correlation and correlation degree of inter-provincial carbon emission transfers of various industries in China, the current paper employed the Moran's I index (Moran, 1950; Lesage, 2004) in Exploratory Spatial Data Analysis (ESDA) to test these aspects. The Moran's I index is here defined as follows (Eq. 8):

$$Moran's\, I_p = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(C_{i,p}-\overline{C_p})(C_{j,p}-\overline{C}_p)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}(C_{i,p}-\overline{C}_p)^2} \tag{8}$$

where: $\overline{C}_p$ is the average carbon emission outflow of the industry ; $C_{i,p}$, $C_{j,p}$ represents the carbon emission outflow of industry p in spatial unit i、j , and W_{ij} is the element of the spatial weight matrix. The elements of spatial weight matrix reflect interdependence and correlation among spatial units from the perspective of exogenous information. Therefore, in order to reduce or eliminate the external influences acting on regions in the current study, it was necessary to determine the spatial weight variables in advance. In the process of regional industrial structure optimization and upgrading, undertaking industrial transfer from economically developed regions to underdeveloped regions, inter-provincial trade comprises the main factors behind carbon emission transfer. This paper also considered the geographical proximity characteristics and industrial structure characteristics of carbon emission transfer, and set the spatial weight matrix elements as $w_{ij} = rook_{ij} \times e_{ij}$, where $rook_{ij}$ reflects the proximity characteristics between provinces and cities, with a setting principle as follows: if the province-city, i is adjacent to the province-city, j, $rook_{ij} = 1$; otherwise, $rook_{ij} = 0$. The regional structure characteristics of the industry p are reflected by the proportion of the p-industry output value, $G_{1,p}$, $G_{2,p}$, L, $G_{n,p}$, of each province to the national total industrial output value, G_p. Based on this, the spatial weight matrix constructed in this paper reflecting the carbon emissions transfer of the p-th industry is defined as follows (Eq. 9):

$$w_{ij,p} = rook_{ij} \times e_{ij,p} = rook_{ij} \times diag(G_{1,p}/G_p, G_{2,p}/G_p, \text{L}\ , G_{n,p}/G_p) \tag{9}$$

The proximity characteristics of the spatial weight matrix were mainly based on the electronic maps provided by the National Geographic Information System website. The proportion of the output value of the six major industries in each province to the total industrial output value of the country was mainly derived from the 2007 and 2010 *China Statistical Yearbooks*. The final spatial weight matrix and Moran's I index were calculated using ArcGIS software.

The absolute value of Moran's I index characterizes the degree of spatial correlation. The larger the absolute value, the greater the spatial correlation, and vice versa. Moran's I index has a value range of [-1, 1]. If it is greater than 0 and close to 1, this means that the carbon emission transfer is positively correlated, and the overall spatial difference is smaller; that is, the provinces with higher (lower) levels of carbon emission transfer are spatially agglomerated If the index value is equal to 0, this means that the carbon emission transfer is randomly distributed (unrelated); if its value is negative and close to -1, this indicates a significant spatial difference in the carbon emissions transfer between a province and its neighboring provinces. The spatial correlation coefficients of the net carbon emission outflow caused by the transfer of the six major industries in 2007 and 2010 are shown in Table 3.

Table 3. Spatial correlation coefficient of carbon emission transfer

	Farming, forest, livestock, and fishery		*Industry*		*Construction*		*Transport and storage*		*Wholesale and retail*		*Other service industry*	
	2007	2010	2007	2010	2007	2010	2007	2010	2007	2010	2007	2010
Moran	0.22	0.11	0.20	0.24	-0.59	0.003	-0.01	-0.02	-0.14	-0.23	0.10	0.18
P	0.04	0.08	0.04	0.04	0.16	0.14	0.03	0.05	0.06	0.09	0.09	0.08

As shown in Table 3, in 2007, industry, farming, forest, livestock, and fishery products, and other service industries show significant spatial positive correlations in terms of carbon emissions transfer. The carbon emission transfer caused by the construction, transport and storage, wholesale and retail industry show certain spatial heterogeneity. In 2010, only the carbon emissions transfer caused by the transfer of industry and other service industries show a significant spatial positive correlation. The carbon emission transfer caused by the construction industry changed from showing a spatial heterogeneity to a spatial correlation. This, in turn, indicates relatively close industrial links among various provinces and cities in China. The carbon dioxide produced by industrial production is being transferred among neighboring provinces and cities. At the same time, the spatial correlation among farming, forest, livestock, and fishery products is weakening over time. The spatial correlation between the construction industry and other service industries is increasing day by day, while the transport and storage, wholesale and retail industry have greater spatial differences.

4. Impact of regional industrial structure on carbon emission transfer

4.1. Model construction and variable selection

Based on the measurement of the scale of embodied carbon emission transfer in inter-provincial trade and the analysis of spatial correlation characteristics, it is necessary to further analyze the driving mechanism of carbon emission transfer. Applications of the structural decomposition method has uncovered that technological effects, structural effects and scale effects are the main factors driving carbon emissions transfer (Wang et al., 2017; Xu and Dietzenbacher, 2014; Gu and Lv, 2016; Pan et al., 2018). However, the method requires multiple data, and cannot reflect the direction and scale of carbon emission transfer between two provinces. This, therefore, makes it difficult to determine how factors such as technological differences and industrial structure differences between provinces and cities affect the transfer of carbon emissions.

As the scale of trade between provinces and cities is large, this is more likely to lead to the transfer of carbon emissions between provinces and cities. This paper regards carbon emissions transfer as a form of regional economic linkage and bilateral trade flow. For this reason, the gravitational model – that can reflect the interaction between two subjects in international trade issues – is suitable to analyze the influencing factors of carbon emission transfer between provinces and cities.

Since the carbon dioxide $C_{i \to j}$ flowing from province and city i to province and city j is different from the carbon dioxide $C_{j \to i}$ flowing from province j to province i - that is, the carbon emissions transfer is directional – this paper introduced a direction vector into the gravity model. The basic equation of carbon emissions transfer is shown in (Eq. 10):

$$C_{i \to j} = C \frac{SS_i SS_j}{DS_{ij}^2} \tag{10}$$

Where: SS_i, SS_j respectively represent the economic development of the province i and the province j, measured in this paper by GDP; DS_{ij} indicates the distance between province i and province j. In the early gravitational model, the distance factor mainly refers to the transportation cost and is usually used as a proxy indicator of whether the boundary is adjacent, or geographical distance (Zwinkels and Beugelsdijk, 2010).

According to the existing structural decomposition results, trade scale, industrial structure, and technical level are the main factors affecting the inflow or outflow of carbon emissions. Inter-regional trade is a prerequisite for carbon emissions transfer. The industrial structure is the basis of the trade structure. Regional industrial structure differences lead to different regional positions in the industrial division of labor and promote inter-regional industrial transfer, especially in areas with an imperfect industrial structure, relying too much on inter-regional trade to meet the final demand. While technology is an important factor in inter-regional trade, the impact of technological distance on inter-regional trade is theoretically uncertain, as it may be an enabler or an impediment. Fu and Luo (2017) found that significant technological gaps between bilateral countries impeded national trade. At the same time, the environment, as an important factor endowment of a country or region, will affect international trade or the international division of labor by changing the comparative competitive advantage. According to the “pollution haven hypothesis” and the “pollution industry transfer hypothesis”, pollution-intensive industries tend to shift to countries with relatively low environmental standards (Copeland and Taylor, 1994). In addition, the stricter a region's environmental regulations, the more the region can force enterprise technology innovation, promote the upgrading of the industrial structure and, ultimately, achieve energy conservation and emissions reduction. Factors such as the industrial structure distance, technical distance and environmental regulation distance affect the transfer of carbon emissions by affecting the scale of trade. It is, therefore, necessary to further expand the distance factor and analyze the indirect impact of industrial structure distance, technical distance and environmental regulation distance on carbon emission transfer.

An advanced industrial structure, also known as the upgrading of industrial structure, refers to the process of transforming the industrial structure system from a lower to a higher level. The advancement of industrial structure generally follows the evolution law of industrial structure and evolves from a primary industry to a tertiary industry. In light of this, the current paper divides the six major industries into three overarching industries: agriculture, forestry, animal husbandry and fishery as the primary industry; industry and the construction industry as the secondary industry; and transportation, warehousing, wholesale and retail, and other service industries as the tertiary industry. This paper uses the ratio of the total output value of the three major industries to GDP to represent the three industrial structures, $ISS_{ip}(p=1,2,3)$, using the latter three structures to construct the industrial structure heightening index, ISH (Eq. 11). An advanced industrial structure can be expressed based on its technical level: the original elements and resources are transferred from an industrial sector with low productivity and technical complexity to an industrial sector with high productivity and technical complexity, thus enhancing the overall productivity and technical complexity. The proportion of high industrial sectors continues to increase, as does the productivity of different industrial sectors. The two main connotations of an advanced industrial structure are, firstly, the change in the proportional relationship and, secondly, the improvement of productivity and technical complexity. That is, the industrial structure-heightening index includes two parts: quantity (proportional relationship) and quality (productivity). The representation of the industrial structure-heightening index of province and city i is as follows (Eq. 11):

$$ISH_i = \sum_{p=1}^{3} ISS_{ip} \times F_{ip} \tag{11}$$

Here, $ISS_{ip}(p=1,2,3)$ represents the three industrial structures (measured by the ratio of the total output value of the three major industries to GDP), and F_{ip} represents the labor productivity (measured by the total industry output divided by the number of employed people) of the industry p in province i.

The greater the proportion of industries with high productivity in the economy, the greater the index of industrial structure.

The industrial structure distances $ISSD_p$ of industry p can be expressed as follows (Eq. 12):

$$ISSD_{ij,p} = [1+(ISS_{i,p} - ISS_{j,p})/(ISS_{i,p}+ISS_{j,p})]^{\gamma_p} \tag{12}$$

Correspondingly, the distance of advanced industrial structure can be expressed as follows (Eq. 13):

$$ISHD_{ij} = [1+(ISH_i - ISH_j)/(ISH_i+ISH_j)]^{\gamma} \tag{13}$$

In the study of industrial structure distance, other distance factors were introduced as control variables. This paper considers the influence of control distances, such as the technical distance (RDD), environmental regulation distance (REGD), adjacent distance (SC), and geographical distance (GD) on the carbon emissions transfer among provinces and cities.

Technical factors are key factors affecting carbon emissions. When the technical levels of the two provinces and cities are different, this may lead to a transfer of carbon emissions. For this paper, the R&D staff scale, RD, was used to measure the technical level of provinces and cities. The difference between provincial and municipal R&D personnel indicates the technical distance, RDD, and its expression is as follows (Eq. 14):

$$RDD_{ij} = [1+(RD_i - RD_j)/(RD_i+RD_j)]^{\lambda} \tag{14}$$

Strengthening environmental supervision and reducing carbon emissions is the key to achieving a win-win situation for economic development and environmental protection. In order to verify whether the "pollution haven hypothesis" held, an environmental regulation distance indicator was constructed for the current paper. The intensity of environmental regulation is represented by $REG = \frac{EI}{GDP} / \frac{Q}{GDP}$. EI denotes the investment amount of industrial pollution control, and Q the industrial benefit. The expression for the environmental regulation distance is as follows (Eq. 15):

$$REGD_{ij} = [1+(REG_i - REG_j)/(REG_i+REG_j)]^{\psi} \tag{15}$$

The indicator SC denotes whether the provinces and cities are adjacent. If they are adjacent, the value is 1, otherwise it is 0. The geographical distance GD is measured according to the spherical distance between provinces and cities.

By introducing the above distance factors into the distance function in Cobb-Douglas form, (Eq. 16) was obtained:

$$DS_{ij}=\sqrt{(\mathbf{2}-SC_{ij})^{\theta}\times GD_{ij}^{\delta}\times ISHD_{ij}\times REGD_{ij}\times RDD_{ij}} \quad (16)$$

The scale variable and Eq. (15) are substituted into the basic gravity model to obtain the carbon emissions transfer gravity expansion model (Eq. 17):

$$C_{i\to j}=\frac{C\times(K\times SS_i^{\alpha})^{\sigma}(K\times SS_j^{\alpha})^{\eta}}{(\mathbf{2}-SC_{ij})^{\theta}\times GD_{ij}^{\delta}\times ISHD_{ij}\times REGD_{ij}\times RDD_{ij}} =\frac{CK^{\sigma+\eta}\times SS_i^{\alpha\sigma}\times SS_j^{\alpha\eta}}{(\mathbf{2}-SC_{ij})^{\theta}\times GD_{ij}^{\delta}\times ISHD_{ij}\times REGD_{ij}\times RDD_{ij}} \quad (17)$$

The logarithm on both sides of the above formula is taken. $C'=CK^{\sigma+\eta}$, $\alpha'=\alpha\sigma$, $\alpha''=\alpha\eta$, $-\theta\mathbf{ln}(\mathbf{2}-SC_{ijt})=(\theta\mathbf{ln}\,\mathbf{2})SC_{ijt}-\theta\mathbf{ln}\,\mathbf{2}$, $\varpi'=\mathbf{ln}\,C'-\theta\mathbf{ln}\,\mathbf{2}$ and $\theta'=\theta\mathbf{ln}\,\mathbf{2}$ are set. For further transformation and simplification, a carbon emissions transfer model from province i to province j could then be obtained (Eq. 18- Eq. 19):

$$\mathbf{ln}\,C_{i\to j}=\varpi'+\alpha'\mathbf{ln}\,SS_i+\alpha''\mathbf{ln}\,SS_j+\theta'SC_{ij}-\delta\mathbf{ln}\,GD_{ij} -\lambda\mathbf{ln}\,RDD_{ij}-\psi\,\mathbf{ln}\,REGD_{ij}-\gamma ISHD_{ij}+\varepsilon_{ij} \quad (18)$$

$$\mathbf{ln}\,C_{i\to j}=\varpi'+\alpha'\mathbf{ln}\,SS_i+\alpha''\mathbf{ln}\,SS_j+\theta'SC_{ij}-\delta\mathbf{ln}\,GD_{ij} -\lambda\mathbf{ln}\,RDD_{ij}-\psi REGD_{ij}-\sum_{p=\mathbf{1}}^{\mathbf{3}}\gamma_p ISSD_{ij,p}+\varepsilon_{ij} \quad (19)$$

Since the carbon emission transfer modelled for this paper was directional, the industrial structure distance factors are also set to have positive and negative directions. In order to investigate whether the industrial structure distances in the positive and negative regions have different effects on carbon emissions, the square of the industrial structure distance is introduced in the model (expressed as $ISSD\mathbf{2}_p$ or $ISHD\mathbf{2}$). Therefore, the above carbon emission transfer models are expanded as follows (Eq. 20- Eq. 21):

$$\mathbf{ln}\,C_{i\to j}=\varpi'+\alpha'\mathbf{ln}\,SS_i+\alpha''\mathbf{ln}\,SS_j+\theta'SC_{ij}-\delta\mathbf{ln}\,GD_{ij} -\lambda\mathbf{ln}\,RDD_{ij}-\psi REGD_{ij}-\gamma ISHD_{ij}+\rho ISHD\mathbf{2}_{ij}+\varepsilon_{ij} \quad (20)$$

$$\mathbf{ln}\,C_{i\to j}=\varpi'+\alpha'\mathbf{ln}\,SS_i+\alpha''\mathbf{ln}\,SS_j+\theta'SC_{ij}-\delta\mathbf{ln}\,GD_{ij} -\lambda\mathbf{ln}\,RDD_{ij}-\psi REGD_{ij}-\sum_{p=\mathbf{1}}^{\mathbf{3}}\gamma_p ISSD_{ij,p}+\sum_{p=\mathbf{1}}^{\mathbf{3}}\tau_p ISSD\mathbf{2}_{ij,p}+\varepsilon_{ij} \quad (21)$$

4.2. Empirical analysis

For the purposes of this paper, the extended gravity model is used to account for the carbon emission transfers between 30 provinces and cities in China in 2010. The scale variables and distance variables obtained in the previous section are taken as explanatory variables, and the important factors affecting the carbon emissions transfer among provinces and cities are analyzed. The empirical results are shown in Table 4.

Table 4 shows the coefficient of the advanced industrial structure distance to be highly positive, and the squared term of the advanced industrial structure distance to be not significant and unstable, indicating that the promoted effect of an advanced industrial structure distance on carbon emissions outflow is a linear one. The industrial structure of a certain area is more optimized, showing that the region mainly develops the tertiary industries or high-tech industries, and the region transfer high energy-consuming and high-pollution industries to other regions, at the same time, carbon emissions of the region transfer to other underdeveloped regions. The development of the tertiary or high-tech industry has caused carbon dioxide to flow from the area of optimized industrial structure to the one with an imperfect industrial structure.

With regarding to the three industry structures, the results show that the impact of different industry structure distances on carbon emission transfer is different. The structure distance of primary industry has a significant positive impact on the outflow of carbon emissions, and the squared term has no significant effect. This is because the development of primary industry is mainly based on farming, forest, livestock, and fishery products, which have a lower impact on carbon emissions, while the rapid growth of the secondary industry occurs at the expense of high-energy consumption and high emissions. If a region mainly develops its primary industry, this indicates that the region will transfer high energy-consuming and high-emission industries to other regions. Therefore, carbon emissions will mainly transfer from those regions where primary industry accounts for a relatively high proportion and to those regions where the primary industries account for a relatively small proportion.

The structure distance of secondary industry is found to have a significant negative impact on the outflow of carbon emissions, and the square term was significantly negative, indicating that the structure distance of secondary industry and the carbon emissions outflow show an "inverted U-shaped" relationship. In order to achieve the specialized division of labor and cooperation, when a region focuses on the development of the secondary industry, other regions will transfer related industries to the region, making the latter a hard-hit area in terms of carbon emissions. At the same time, the results show that when the structure distance of secondary industry is small, as the distance increases the carbon emissions will flow from an area of secondary industry accounting for a small proportion to an area of secondary industry accounting for a large proportion.

Table 4. Influencing factors of carbon emission outflow

Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
SS_i	0.79*** (19.88)	0.73*** (18.91)	0.96*** (13.15)	0.99*** (14.19)	0.81*** (12.45)	0.89*** (24.17)
SS_j	0.85*** (21.49)	0.84*** (21.70)	0.72*** (11.41)	0.62*** (10.20)	0.70** (12.01)	0.71*** (18.95)
$\ln RDD$			0.26*** (2.97)	033*** (3.86)	0.11 (1.30)	
$\ln REGD$			0.08 (1.15)	0.09 (1.29)	0.12* (1.78)	
SC		0.54*** (4.58)		0.55*** (4.73)	0.43*** (4.22)	
$\ln GD$		-0.19*** (-2.73)		-0.22*** (-3.22)	-0.21*** (-3.45)	
$\ln ISSD_1$					0.65*** (3.68)	0.66*** (3.69)
$ISSD2_1$					-0.02 (-0.31)	-0.05 (-0.72)
$\ln ISSD_2$					-2.47*** (-3.76)	-2.08*** (-3.27)
$ISSD2_2$					-5.00*** (-4.35)	-5.15*** (-4.30)
$\ln ISSD_3$					-1.10 (-1.34)	-0.50 (-0.62)
$ISSD2_3$					4.18*** (2.96)	4.84*** (3.30)
$ISHD$	0.52*** (3.81)			0.39*** (3.00)		
$ISHD2$	-0.25 (-1.02)			0.11 (0.44)		
C	-14.53*** (-27.58)	-12.62*** (-15.69)	-14.92*** (-27.26)	-12.86*** (-16.16)	-11.77*** (-16.46)	-14.03*** (-29.12)
R^2	0.50	0.53	0.50	0.55	0.65	0.62

*Note: ***, ** and * respectively denotes significance at 1%, 5% and 10% level, with t-values in brackets.*

Nevertheless, when the structure distance of the secondary industry increases to peak value, the distance grows larger and the carbon emissions outflow is hindered. Regions with a higher proportion of secondary industries tend to cooperate with other regions with similar structures, resulting in carbon emissions flowing among regions with similar industrial structures.

The structure distance of the tertiary industry is found to have a less significant negative impact on the carbon emissions outflow, and the square term is significantly positive, indicating that the tertiary industry structure distance and the carbon emissions outflow show a "U-shaped" relationship. The tertiary industry is based on the service industry and has the least impact on carbon emissions. When a region focuses on the development of tertiary industries, industries with high energy consumption and high emissions will inevitably have been transferred to other regions, thus leading to the transfer of carbon emissions. When the structure distance of the tertiary industry is small, the increase in distance will hinder carbon emissions flowing from areas with a relatively small proportion of tertiary industry to areas with a larger proportion of the same. However, when the structure distance of the tertiary industry reaches a peak value, an increase in the distance will promote carbon emissions flowing away from areas with a relatively high tertiary structure to areas with imperfect development of the latter.

The key to industrial structure optimization lies in improving the technical level. In this paper, the technical distance among different regions has a positive impact on the carbon emissions outflow, indicating that the more R&D personnel in a certain region, the higher the technical level and the greater the capacity for the development of clean industries. The outward transfer of polluting industries has led to the transfer of carbon emissions from technologically advanced areas to technologically backward ones. The environmental regulation distance has a positive effect on carbon emissions outflow. This is because areas with strict environmental regulation pay more attention to pollution control and supervision. Setting a high barrier to entry for polluting industries leads to the transfer of these industries away from areas with strict environmental regulation to those with looser regulation, which, in turn, leads to a shift in carbon emissions, thus verifying the existence of the "pollution haven hypothesis".

At the same time, this study finds that the adjacent distance has a significant positive impact on carbon emissions, indicating that carbon emissions are more prone to transfer among adjacent provinces and cities. Geographical distance is found to have a significant negative impact on the carbon emissions outflow, indicating that the farther apart the regions are, the less likely it is that the carbon emissions will be transferred; that is, there occurs a proximity effect of carbon emissions in China. The provincial economic scales have a significant positive impact on carbon emissions, indicating that economic scale is an important factor leading to the transfer of carbon emissions. Maintaining a regional economic aggregate balance is the key to curbing carbon emission transfer.

5. Conclusions

The impulse towards increasing local GDP growth, especially that arising from the catch-up incentives of the central and western regions with underdeveloped economies, is the main cause of China's growing carbon emissions. In response to the call of the international community to develop a low-carbon economy, the Chinese government promised to reduce carbon dioxide emissions per unit of GDP by 60%-65% in 2030 compared to 2005. In 2020, non-fossil energy accounted for 15% of the country's primary energy consumption. At the same time, the 19th National Congress of the Communist Party of China (CPC) proposed further to expand the energy conservation and environmental protection industry, the cleaner production industry and the clean energy industry, and to promote the energy production and consumption revolution, build a clean, low-carbon, safe and efficient energy system, and emphasize the structural carbon emissions reduction by adjusting the industrial structure. The adjustment of industrial structure is inseparable from the analysis of regional industrial structure optimization and regional industrial transfer.

Industrial restructuring forms an important basis for the successful completion of carbon emission reduction targets. In China, industrial policy is formulated based on its factor endowment by region, whereby the planning of industrial distribution within a region will not only promote the effective distribution of resources among regions and economic and trade cooperation, but will also help to promote the realization of the overall energy saving and emission reduction targets. There exist significant differences in the industrial structure, technology level and environmental regulation policies across China's provinces. The spatial difference between structural emission reductions and policies on emission reductions further leads to the transfer of carbon emissions. Therefore, a quantitative analysis of the impact of regional industrial structure differences and environmental regulation differences on carbon emissions transfer in China, such as that presented in the current study, may act as an important reference point for the implementation of structural emissions reduction and policies on the latter, as well as help regions to share the responsibility of carbon emissions reduction in a fair and reasonable manner.

This paper constructs a multi-regional input-output model to measure the carbon emissions of China's 30 provinces and cities in 2007 and 2010. The results show that the embodied carbon emissions tend to transfer from economically developed regions and regions with a single industrial structure to economically underdeveloped regions, or resource-intensive regions. Furthermore, this paper constructs a spatial weight matrix containing geographic proximity features and regional industrial structure characteristics and considers the spatial characteristics of carbon emission transfers at the industry level. The results show that the spatial correlation of farming, forest, livestock, and fishery products, industry and other service industries is relatively close, resulting in the transfer of carbon dioxide produced by the above industries between neighboring provinces and cities, while the spatial differences between the transportation, warehousing and wholesale and retail industries are greater, with the resulting carbon emissions shift not showing the characteristics of spatial clusters.

Finally, the directional gravity model is used to analyze the impact of regional industrial structure distances on the outflow of carbon emissions. The results show the technical distance, industrial structure distance and environmental regulation distance are found to have a positive impact on carbon emissions, whereby carbon dioxide emissions are transferred from high-tech, strictly environmentally-governed areas with an optimized industrial structure to low-tech and less regulated areas with a more backward industrial structure. At the same time, industry was categorized and the impact of structural differences on carbon emissions analyzed. The results here showed that the primary industrial structure distance promotes the outflow of carbon emissions, and that the second industry structure distance and carbon emissions outflow show an "inverted U-shaped" relationship. The tertiary industry structure distance and carbon emissions outflow show a "U-shaped" relationship; that is, the transfer of carbon dioxide emissions is prone to take place in provinces and cities that had similar industrial structures. Moreover, the transfer tends to come from those provinces and cities dominated by agriculture and the service sector and move to provinces and cities dominated by industry.

According to the above research conclusions, policy makers should consider the differences in resource endowment and technological development of different regions, formulate differentiated industrial structure adjustment plans, and rationally plan for inter-regional industrial transfer; these actions would help to achieve national and regional carbon emission reduction targets. At the same time, it is necessary not only to pay attention to the calculation and distribution of carbon emission responsibilities between provinces and cities, but also to establish accounting standards for the production and consumption-sharing responsibility based on the carbon emissions of industrial transfer, as well as to consider the impact of inter-regional trade in accounting for local carbon emissions and allocating relevant responsibilities. To a certain extent, it is more advantageous to enact regional cooperation in reducing CO_2 emissions, rather than individual provinces and regions doing this alone. The findings of the current paper thus lead to the recommendation of forming a trading mechanism based on inter-regional carbon transfer, in order to better promote the cooperation between provinces and cities. Finally, industry access standards should be improved, and the transfer of high-carbon emission industries should be strictly limited, to reduce carbon emissions from the development of heavy industry and promote the realization of the national energy-saving and CO_2 emission reduction targets.

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