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Research article

Research on the carbon reduction effect of regional industrial transfer in China -- based on the perspective of factor flow

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ABSTRACT

Industrial transfer plays a crucial role in regional carbon reduction efforts in China. This study conducted a systematic analysis of the carbon reduction impact of industrial transfer, focusing on factor flow, and performed empirical tests using Chinese provincial data from 2003 to 2019 with a spatial regression model. The key findings are as follows: (1) Industrial transfer significantly influences carbon emissions, with varying effects depending on the factor flow. Capital and technology flows contribute to carbon emission reduction, while labor flow generally has a negligible impact. (2) Over time, the environmental impact of capital and technology flows intensifies, whereas the influence of labor flow diminishes. (3) Regional variations exist in the impact of industrial transfer on carbon emissions based on the factor flow perspective.

1. Introduction

Reducing carbon emissions is an important issue of global concern [1]. In September 2020, President Xi Jinping sincerely pledged to the international community that China will peak its CO_2 emissions by 2030 and achieve carbon neutrality by 2060 [2]. The Chinese government actively promotes economic restructuring and industrial transformation and upgrading, and the trend of industrial transfer between different regions is becoming more and more obvious, and industrial transfer has become an important means of carbon emission management. At present, China's industrial transfer is mainly based on the policy-guided industrial transfer under the direction of the carbon peak and carbon neutral dual-carbon target. China's industrial transfer is mainly manifested in the transfer of high-polluting industries from the east and central regions to the central and western regions, as well as the industrial transfer generated by the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta Economic Circle in order to achieve industrial agglomeration and optimization [3]. This kind of inter-regional industrial transfer can realize effective and reasonable allocation of factors, achieve coordinated regional development and optimization and upgrading of industrial structure, and produce win-win results of economic growth and environmental quality improvement [4].

Although industrial transfer can effectively promote regional economic growth, it can also generate environmental problems [5,6]. Due to the differences in research methods and samples, the conclusion of whether industrial transfer is conducive to improving environmental quality remains controversial [7]. While industrial transfer is essentially factor flow, studies have largely been carried out from a single perspective of industrial transfer [8]. Analyzing from the perspective of factor flow can further differentiate the environmental effects of industrial transfer. In addition, less consideration has been given to the spatial spillover effect and correlation

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characteristics of industrial transfer. Industrial transfer is influenced by factors that flow between neighboring regions, and the industrial transfer of a region will have an important impact on the surrounding region's economic growth and environmental governance.

Using data from 30 provinces in China as the research sample, this study systematically analyzed the impact of labor, capital, and technology flow on carbon emissions in industrial transfer from the perspective of factor flow. (1) By investigating the carbon reduction effects of different factors involved in industrial transfer in China, this study offers novel research insights into the connection between industrial transfer and carbon emissions. (2) Enhancing the understanding of the interaction between industrial transfer and carbon emissions, the study delves into the impact mechanism of three flow factors. (3) By taking into account the spatial spillover effect and spatial correlation characteristics of industrial transfer's impact on carbon emissions, the paper conducts a detailed analysis of the regional and temporal variations in the carbon reduction effects of industrial transfer, thereby providing guidance for local governments to enhance their carbon reduction efforts.

2. Literature review

There are three main conclusions about the impact of industrial transfer on the environment (including carbon emissions). First is the "Hypothesis of Pollution Haven" (HPH), which argues that developed countries transfer pollution industries that do not comply with their own environmental regulations into less developed countries with lower environmental standards, resulting in the environmental pollution transfer to less developed countries and the creation of pollution shelters [9–13]. Ma and Zhang(2014) found that industrial transfer has led to pollution spillover, which makes the blackening of industrial structures in the neighboring region the price of green adjustment; thus, industrial transfer perpetuates the benefiting of oneself at the expense of others [8]. Dong and Bai(2015) concluded that the transfer of high-polluting industries from the eastern region to the central and western regions has directly led to environmental pollution and damage in the central and western regions [14]. Zhang and Lin(2017) found that international and interregional industrial transfers have increased carbon emissions, and the latter has a more direct and broader impact [15]. Liao and Xiao (2017) pointed out that the central region of China is becoming an active area for industrial transfer and carbon transfer, with industrial transfer increasing the region's carbon emissions to a certain extent [16]. Li et al.(2018) concluded that the industrial transfer in developed regions of China had deepened the spatial connection between the provincial economy and carbon emissions, and the spillover effect of carbon emissions has gradually emerged [17]. Qin and Ge (2019) discovered that as the relative intensity of environmental regulations shifts from low to high, the environmental pollution issues stemming from the relocation of high-polluting industries have exacerbated [18]. Liu(2020) found that industrial transfer in the coordinated development of Beijing, Tianjin, and Hebei could not fundamentally control carbon dioxide emissions [19]. Shen and Ren (2021) found that the transfer of highly polluting industries from some regions of China to areas with weak environmental regulations will lead to pollution transfer and increase environmental pollution in the transferring places [20].

The second viewpoint is that transferring polluting industries is conducive to pollution control and improves the environmental quality of areas where industries move. By undertaking industrial transfer and adopting advanced clean technology, the "pollution halo" is formed to improve environmental quality. Also, undertaking international industrial transfer can promote the sustainable development of the host country's economy and benefit to environmental protection. Sometimes, the environmental protection management system of the transferred industry itself is more comprehensive, and the implementation of clean production technology is more thorough, ultimately improving the environmental effect [17]. Cagno et al. (2014) found that the industrial transfer accompanied by industrial upgrading has improved the environmental effect in Guangdong Province [21]. Wang et al.(2017) posit that industrial transfer in international trade can lead to changes in carbon emissions in specific industries [22]. Chen et al. (2017) determined that the industrial transition in the Pearl River Delta region, particularly within labor-intensive and technology-intensive sectors, aids in restraining the growth of regional carbon emissions [23]. Through an analysis of data from 30 administrative regions in China from 2004 to 2017, Zhao and Fan (2019) found that industrial transfer can alter the spatial distribution of regional energy intensity by impacting the regional industrial structure, resulting in the convergence of energy intensity [24]. Meanwhile, Liu et al. (2020) discovered that internal industrial transfer within the Beijing-Tianjin-Hebei region can contribute to environmental improvement [25]. Wu et al.(2021) identified a positive correlation between the transfer of Chinese manufacturing industry to Thailand and the carbon emissions from trade between the two nations, which helps to alleviate China's energy conservation and emission reduction pressure [26]. Xiong and shi (2021) analyzed the energy efficiency of the regions that undertook Chaney's transfer and found that these regions improved their energy efficiency by 12 %, which contributed to the reduction of regional carbon emissions in China [27]. Furthermore, Yu and Zhang (2022) identified the causal effects of the industrial transfer policy (ITP) on carbon emissions,and found that the industrial transfer policy leads to mitigate carbon emissions by approximately 4.7 million tons. emissions in China [28]. Bai et al. (2023) found that the combination of digital economy and industry transfer can reduce carbon emissions in China [29].Song et al. (2023) found that carbon emission reduction policies and the level of industrial transfers in different regions are key factors influencing China's achievement of carbon neutrality targets [30].

In addition, the impact of industrial transfer on the regional environment is uncertain. Due to the spatial differences in industrial transfer, its impact on the ecological environment exhibits dynamic variability. Soboleva and Mashkov (2015) found that industrial transfer was accompanied by pollution transfer. Xu et al.(2017) concluded that industrial and carbon transfer relationships display an inverted U-shaped pattern. Before the threshold, every 1 % increase in industrial transfer resulted in a 0.327 % increase in industrial carbon transfer; after the peak, the industrial carbon transfer decreased by 0.07 % [31]. Liu and Dong (2019) suggested that industrial transfer could effectively alleviate the degree of haze pollution in the transferred-out areas but would significantly accelerate haze pollution in the transferred-in areas [32]. Gu et al.(2020) found that the total carbon emission efficiency of China's interregional industrial transfer improved in 2005–2015; the highest total factor carbon emission efficiency was in the eastern coastal region, followed by the northeast region, while the central and western regions had been ineffective [33]. Dong et al.(2021) using 42 national samples, discovered that the effect of industrial transfer on carbon emissions is less pronounced in developed countries when compared to developing countries. They found that the influence of foreign factors on carbon emissions in developing countries was approximately 30 % higher than in developed countries [34]. Yang et al. (2023) found that there is a certain degree of significance in the environmental improvement of China's industrial transfer demonstration zones, but this positive impact varies depending on the natural resources, capital accumulation and technological innovation capacity of different cities, and even the improvement effect is not significant [35].

The impact of industrial transfer on the environment is indeed a contentious issue, with conclusions varying significantly based on the research methods and samples utilized. For example, studies have indicated that industrial transfer within the Beijing-Tianjin-Hebei region does not exacerbate local environmental pollution. Conversely, research has also demonstrated that industrial transfer in the central region can result in pollution leakage. This discrepancy in findings underscores the complexity of the matter and emphasizes the necessity for more nuanced and context-specific research [36]. From the perspective of industrial transfer, industrial transfer involves many aspects, such as factor flow, capacity change, and industrial structure adjustment. A region may be transferring high-polluting industries out or accepting high-polluting industries. The effects of industrial transfer in a region can be properly measured by considering the comprehensive impact of industrial transfer in and out. The essence of industrial transfer is the flow of production factors in different spaces, mainly reflected in the movement of labor, capital, and technology factors [37]. From the perspective of factor flow, we can more comprehensively analyze the overall situation of industry transfer in and out of a region and objectively assess the overall effect of industry transfer on the environment. While many previous studies (e.g., Li and Ma (2017) [38], Sun et al. (2021) [39]) analyzed the impact of industrial transfer on economic growth from the perspective of labor flow, they were unable to comprehensively evaluate the environmental effects of various factors in industrial transfer.

3. Materials and methods

3.1. Variable description and measurement

(1) Carbon emissions(see Fig. 1), this study uses total carbon emissions to measure the level of carbon emissions in a region. Drawing lessons from the analysis by the Intergovernmental Panel on Climate Change, in this study, carbon emission was determined by calculating the product of the total energy utilization and the energy consumption coefficient. Eight different types of consumed energy were included in the calculations: coal, hard coke, crude oil, gasoline, kerosene, diesel, fuel oil, and natural gas. The aggregate of the values was then used as the total carbon emissions [40].

(2) Industrial transfer. The measurement methods of industrial transfer in existing research mainly consist of three aspects. Firstly, based on the notion that industrial transfer leads to a reduction in environmental pollution and the outdated production capacity of polluting industries in the region, the change in output value of pollution-intensive industries or the change in regional gross output value can be utilized to depict the level of industrial transfer [41,42]. The second is calculating the industrial gradient coefficient to reflect the regional level of industrial transfer [43]. Third, from the perspective of factor flow, industrial transfer is regarded as the spatial flow of factors, and the level of industrial transfer in a region is described by the flow of labor force, capital and technology [37]. For this study, using the perspective of factor flow, the inter-regional industrial transfer is determined by measuring the spatial flow of labor, capital, and technology factors (see Fig. 2).

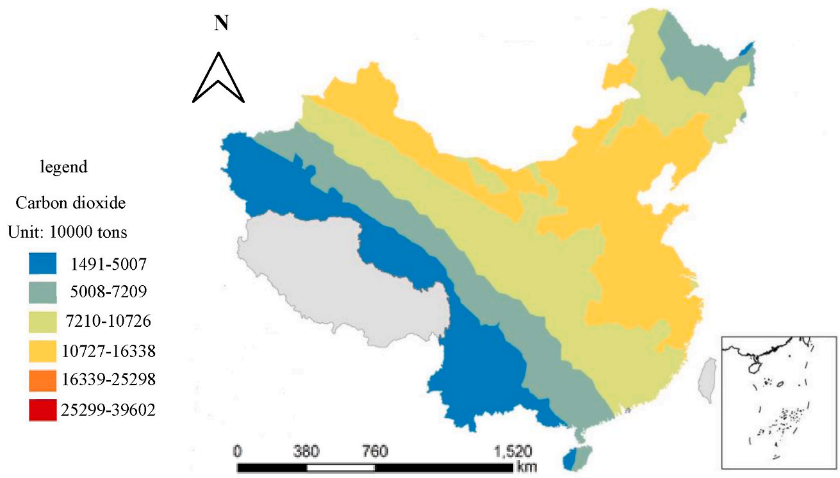

Fig. 1. China's carbon emissions in 2019.

① Labor flow (Laf) level. Labor mobility is primarily manifested as a type of employment mobility. Drawing on the methodology of Fujita and Henderson (2014) [44] and Zhang (2016) [37], the corresponding natural growth factors are removed from the total population change in each region to calculate the population mechanical growth rate, which reflects the flow of labor factors. The calculation formula is:

$$Laf_{it} = \frac{L_{it}}{L_{i(t-1)}} - K_{it} \tag{1}$$

where L_{it} represents the population of area *i* at the end of period *t*, and K_{it} represents the natural population growth rate of area *i* at the end of period *t*.

② Capital flow level (Caf). By utilizing the method outlined by Li and Chen (2020) [45] as a reference to measure the capital flow for each area, the relative change of the total fixed capital stock can be determined. The calculation formula is:

$$Caf_{it} = \frac{I_{it}}{\sum_{i=1}^{N} I_{it}} - \frac{I_{i(t-1)}}{\sum_{i=1}^{N} I_{i(t-1)}} \tag{2}$$

where I_{it} represents the total fixed capital stock of region i in the period t.

③ Technology flow level (Taf). It mainly reflects the scale of technology transfer and diffusion between regions. Based on the practice of Liu (2020) [46], the regional technical market turnover can be used to measure the level of technology flow in a region.

(3) Control variables. This study seeks to augment existing research by incorporating several control variables - economic development level (GDP), foreign direct investment (FDI), industrial structure (IS), environmental regulation (ER), and energy consumption level (EC). These are all significant factors that can influence carbon emissions. The GDP per capita is used to assess the level of economic development, while the total investments from foreign investors per capita represent FDI [45, 47–50]. The level of energy consumption per capita is determined by the energy consumption in a specific region. The regional industrial structure is defined by the percentage of the secondary industry, and the total regional pollution investment is used to measure the strength of environmental regulation. The total regional energy consumption determines the level of energy consumption. This comprehensive approach provides a more in-depth analysis of the various factors that can impact carbon emissions [51–53].

3.2. Empirical model design

The environmental Kuznets curve (EKC) is a hypothesis that suggests as an economy grows initially, environmental degradation and pollution increase, but after a certain point (turning point), with further growth, it decreases. This principle was first proposed by Grossman and Krueger in 1994 [54]. The basic model for the relationship between environmental pollution and the level of economic development can be represented as:

$$\ln CO2 = \alpha_0 + \alpha_1 lnGDP + \alpha_2 \, ln^2 \, GDP + \alpha_3 lnX + \varepsilon, \varepsilon \sim N\left(o, \delta^2\right) \tag{3}$$

where X is the set of control variables, and ε is the following error term. *lnGDP* and ln^2 *GDP* represent per capita GDP and its square term, respectively. Industrial transfer and control variables are added into formula (4) to form model (5).

$$\begin{aligned} \ln CO2_{it} = {} & \alpha_0 + \alpha_1 \, ln \, GDP_{it} + \alpha_2 \, ln^2 GDP_{it} + \alpha_3 \, ln \, LAF_{it} + \alpha_4 lnCAF_{it} + \alpha_5 \, ln \, TAF_{it} \\ & + \alpha_6 \, ln \, \mathrm{FDI}_{it} + \alpha_7 \, ln \, IS_{it} + \alpha_8 \, ln \, ER_{it} + \alpha_9 \, ln \, EC_{it} + \varepsilon_{it}, \varepsilon_{it} \sim N\left(o, {\delta_{it}}^2\right) \end{aligned} \tag{4}$$

where $lnCO2_{it}$ is total carbon emissions; $ln \, LAF_{it}$,$lnCAF_{it}$, and $ln \, TAF_{it}$ refers to the level of labor flow, capital flow, and technology flow in industrial transfer; $ln \, \mathrm{FDI}_{it}$, $ln \, IS_{it}$, $ln \, ER_{it}$, and $ln \, EC_{it}$ indicate the FDI, industrial structure, environmental regulation, and energy

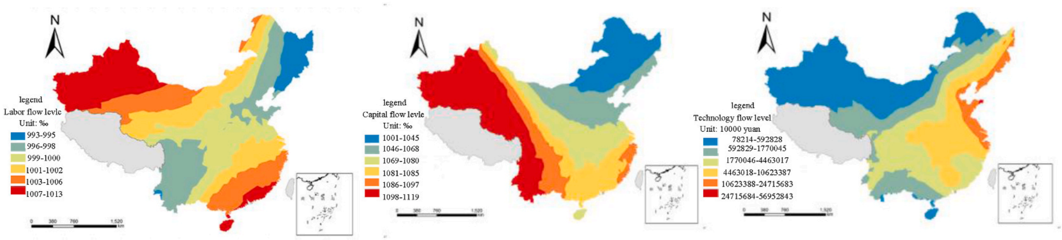

Fig. 2. Industrial transfer in 2019.

consumption.

The Spatial Lag Model (SLM) and Spatial Error Model (SEM) are spatial econometric models that take into account the spatial dependence and interaction between various regions. As such, this study employs a spatial econometric model to formulate the regression equation, with the expressions of the classical SLM and SEM models presented as follows:

$$\begin{aligned} lnCO2_{it} &= \rho WlnCO2_{it} + \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln^2 GDP_{it} + \alpha_3 \ln LAF_{it} + \alpha_4 lnCAF_{it} \\ &+ \alpha_5 \ln TAF_{it} + \alpha_6 \ln FDI_{it} + \alpha_7 \ln IS_{it} + \alpha_8 \ln ER_{it} + \alpha_9 \ln EC_{it} + \varepsilon_{it},\ \varepsilon_{it} \sim N\left(o, \delta_{it}{}^2\right) \end{aligned} \tag{5}$$

$$\begin{aligned} lnCO2_{it} &= \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln^2 GDP_{it} + \beta_3 \ln LAF_{it} + \beta_4 lnCAF_{it} + \beta_5 \ln TAF_{it} \\ &+ \beta_6 \ln FDI_{it} + \beta_7 \ln IS_{it} + \beta_8 \ln ER_{it} + \beta_9 \ln EC_{it} + \varepsilon_{it} \end{aligned}$$

$$\varepsilon_{it} = \lambda W \varepsilon_{it} + \phi_{it}, \phi_{it} \sim N\left(0, \sigma_{it}^2\right) \tag{6}$$

where $wlnCO2_{it}$ is the spatial lag variable, ρ is the spatial spillover effect, λ is the spatial autocorrelation coefficient, and ϕ_{it} is the random error vector of normal distribution.

3.3. Data

The empirical study encompassed 30 provinces in China, utilizing data spanning from 2003 to 2019. The Tibet province was excluded due to insufficient data. Primary data sources enlisted for this analysis include the "China Statistical Yearbook", "Statistical Yearbook of China's Population and Employment", "China Statistical Yearbook on Environment", and "China Industrial Yearbook". To effectively mitigate the complexity introduced by the time-series dimension, a logarithmic transformation was implemented during the analytical process. The variable description and statistical results are summarized in Table 1.

4. Results

4.1. Model selection

In order to assess the spatial autocorrelation traits of variables and validate the reliability of the chosen spatial econometric model, the spatial autocorrelation properties of all explanatory variables were initially examined. The summary of Moran's I values for the explanatory variables is provided in Table 2.

As illustrated in Table 2, the Moran's I values for labor flow did not show statistical significance in 2005 and from 2015 to 2019 but were significant in the other 11 years of the study. Similarly, the Moran's I values for capital flow showed significance for 12 out of the 17 years studied, and those for technology flow were significant for 8 years. Moreover, the Moran's I values for both GDP and FDI consistently displayed significance throughout all the years studied. Other variables also showed significance for a substantial number of years. Fig. 3 provides a representation of the Global Moran's I index for carbon emissions from 2003 to 2019. As can be seen in Figs. 3 and 18 regions were located in the one-three quadrant in 2003 and 2009, 20 regions were located in the one-three quadrant in 2005, 19 regions were located in the one-three quadrant in 2007, 2013, 2015 and 2017, 17 regions were located in the one-three quadrant in 2011 and 14 regions were located in the one-three quadrant in 2019. Overall, the number of regions located in quadrants 1 and 3 in the observed years exceeds 60 per cent, which also indicates that the spatial positive autocorrelation of carbon emissions in China is more significant. This evidence suggests that a spatial econometric model would be the most appropriate choice for the empirical analysis.

The SLM and SEM models were then compared; the model results are shown in Table 3. The LM test value of the spatial lag model was 21.9727 with a p-value of 0.000, while the LM robustness test value was 35.9364 with a p-value of 0.000. For the spatial error model, the LM and robustness LM test values were 6.8566 and 20.8202, respectively. The results suggest that the SLM and SEM models passed the significance test, with the SLM being more significant. At the same time, according to the research of Shao (2019) [55], the fixed effect model is the first choice when the regression analysis is limited to specific individuals; thus, the empirical analysis in this study was based on the fixed effect model.

Table 1
Descriptive statistics of variables.

Variables	Description	Minimum	Maximum	Mean	Std. Deviation
$lnCO_2$	Carbon emissions	6.0369	10.5866	8.8482	0.7888
lnLAF	Labor flow	4.5641	9.2123	6.9094	0.1462
lnCAF	Capital flow	6.9071	7.3088	7.0432	0.0492
lnTAF	Technology flow	7.5418	17.8577	13.0876	1.8659
lnGDP	Economic development level	8.0886	12.0090	10.3187	0.7516
lnFDI	FDI	1.3438	7.7219	5.1224	1.6857
lnIS	Industrial structure	2.4713	4.0817	3.6399	0.2584
lnER	Environmental regulation	1.2809	7.2557	4.8357	1.0876
lnEC	Energy consumption	1.7970	10.6308	3.4484	1.6330

Table 2
Moran's I values of explanatory variables.

Years	LAF	CAF	TAF	GDP	FDI	IS	ER	EC
2003	0.0587	−0.0773	−0.0846	0.4057***	0.4048***	0.0793	0.2709***	0.1783**
2004	0.1924**	−0.0706	−0.0597	0.4123***	0.3128***	0.0678	0.2734***	0.1796*
2005	0.2503***	−0.0339	−0.1231*	0.4253***	0.3410***	0.0929	0.3041***	0.1839**
2006	0.2816***	0.1200*	0.0155	0.4304***	0.3125***	0.0376	0.2674***	0.1820**
2007	0.2816***	0.1839**	0.0113*	0.4270***	0.3032***	0.0740	0.3599***	0.1798**
2008	0.3283***	0.2468**	0.0653*	0.4323***	0.2725***	0.0487	0.3185***	0.1775**
2009	0.3018***	0.0916	0.0649	0.4324***	0.2384**	0.0193	0.3094***	0.1709*
2010	0.2370***	0.0815	0.1785**	0.4397***	0.1945**	0.0318	−0.0071	0.1663*
2011	0.2858***	0.1094*	0.1601*	0.4337***	0.1632**	0.0432	0.2805***	0.1514*
2012	0.3018***	0.2188**	−0.1148*	0.4201***	0.1956**	0.0236	0.2380***	0.1405*
2013	0.2409***	0.2277**	−0.1936*	0.4103***	0.3598***	0.0128	0.2767***	0.1362*
2014	0.2261***	0.2795**	−0.0494	0.3945***	0.2349**	−0.0083	0.2355**	0.1231*
2015	0.0442	0.2540**	−0.0638	0.3949***	0.4245***	−0.0100	0.1821**	0.1213*
2016	−0.1354	0.3260***	−0.0439*	0.4101***	0.5282***	−0.0006	0.1905**	0.1122
2017	−0.0395	0.1827*	−0.0009	0.4392***	0.4814***	0.0900	0.2611**	0.0965
2018	−0.0368	0.1841**	0.0071	0.4306***	0.4276***	0.0287	0.3009	0.0983
2019	−0.0398	0.1851**	0.1199*	0.3629***	0.4471***	0.1587*	0.3079***	0.0845

Note: ***, ** and * indicate the significance at 1 %, 5 %, and 10 % levels, respectively.

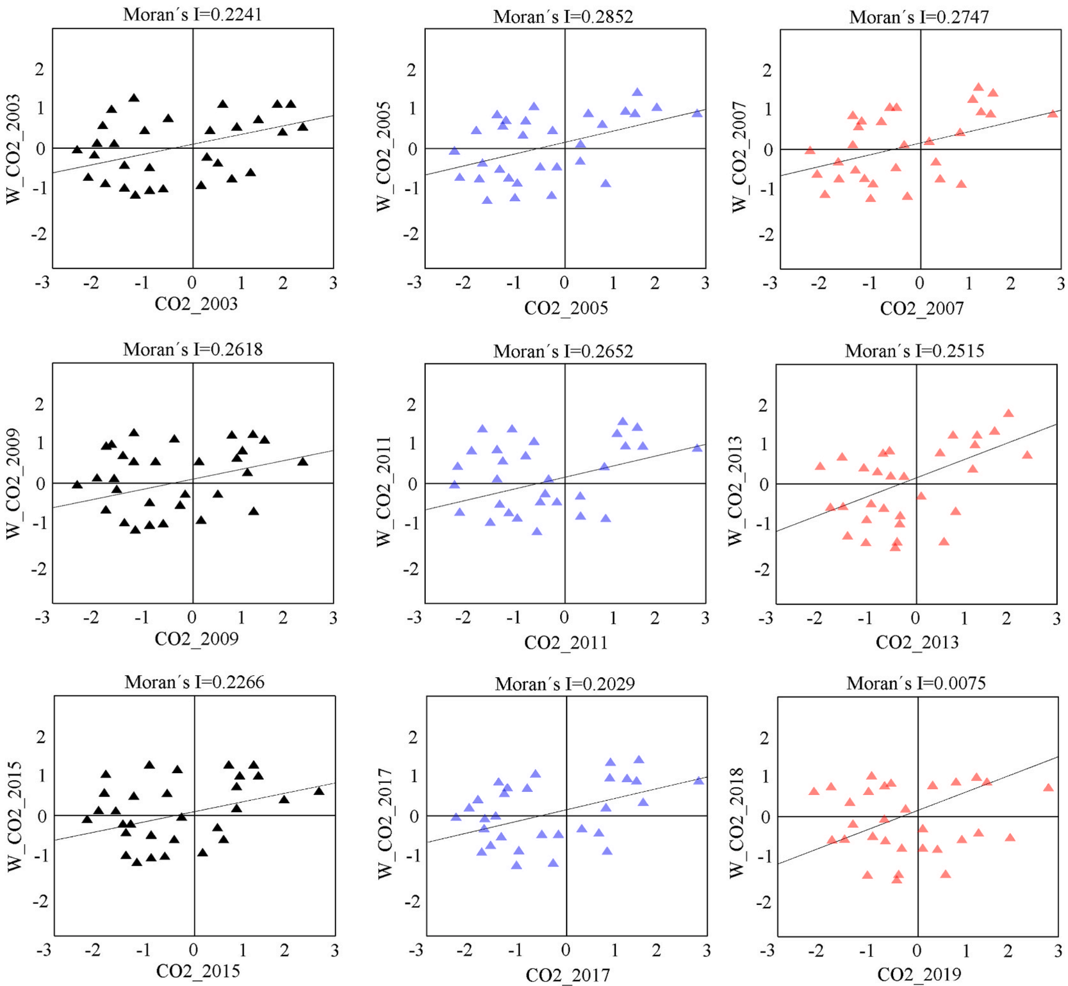

Fig. 3. Moran scatterplots of carbon emissions.
Note: Triangles represent the 30 provinces, with quadrants 1, 2, 3, and 4 rotated clockwise from the upper right in the coordinate axis.

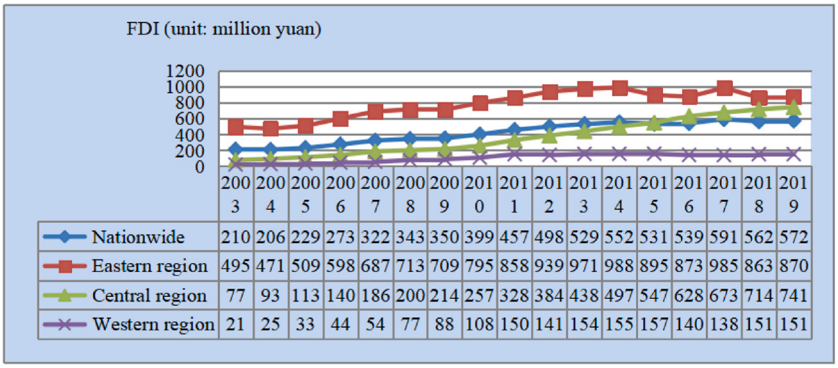

Fig. 4. the average level of FDI introduction for three regions during 2003–2019.

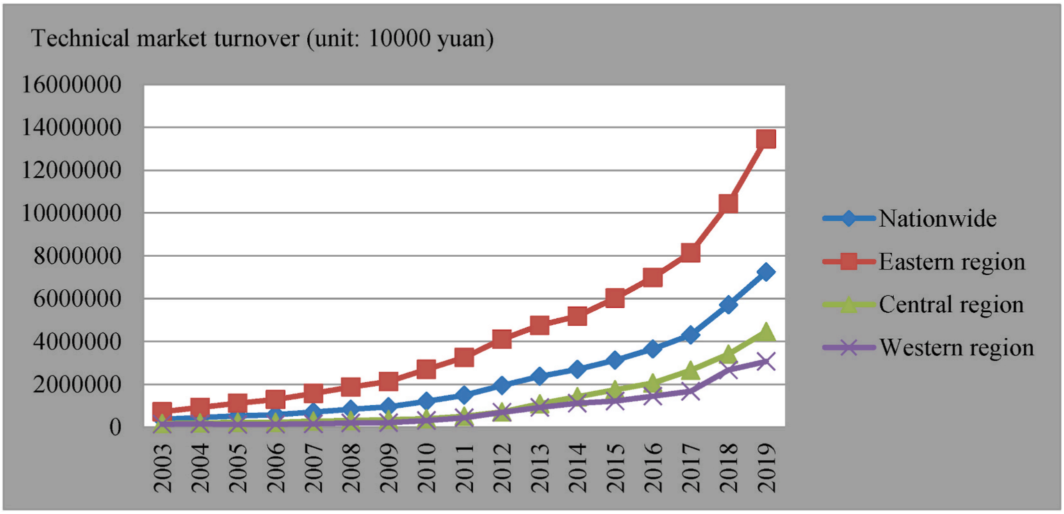

Fig. 5. the average level of technical market turnover for three regions during 2003–2019.

Table 3
Comparative results of SLM and SEM Model.

Testing method	Test statistics	P-value
LM test no spatial lag, probability	21.9727	0.000
robust LM test no spatial lag, probability	35.9364	0.000
LM test no spatial error, probability	6.8566	0.009
robust LM test no spatial error, probability	20.8202	0.000

4.2. Analysis of carbon reduction effect of industrial transfer

Table 4 presents a summary of the impact of industrial transfer on carbon emissions, as assessed by the space fixed effect model (SFE), time fixed effect model (TFE), and time and space fixed effect model (STFE). Examining the ρ/λ values, all were found to be statistically significant in both the SLM and SEM models, which implies the existence of substantial spatial spillover effects in China's carbon emissions. This underscores the importance of incorporating spatial considerations in our empirical assessment. In general, the outcomes obtained from the SLM and SEM models were quite similar. The spatial fixed effect model (SFE), however, outperformed the other models in terms of adjusted R^2, with the SLM's SFE model displaying marginally superior explanatory capacity. Consequently, the forthcoming empirical findings are primarily based on the SFE model of the SLM model.

The impact of labor flow on carbon emissions is not significant in the process of industrial transfer. From Table 4, the estimated coefficients of lnLAF in the SLM model were 0.0112, 0.0050, and 0.0028, while the estimated coefficients in the SEM model were 0.0112, 0.0073 and 0.0037; all were not statistically significant. The estimated coefficients in each model were positive, indicating that labor flow exacerbated regional carbon emissions, although this effect is not statistically significant. China's labor flow primarily

Table 4
Estimated results of the impact of industrial transfer on carbon emissions.

Variables	SLM			SEM		
	SFE	TFE	STFE	SFE	TFE	STFE
lnLAF	0.0112 (0.2814)	0.0050 (0.0431)	0.0028 (0.0715)	0.0112 (0.2788)	0.0073 (0.0631)	0.0037 (0.0939)
lnCAF	−0.1788* (−1.6851)	−1.7202*** (−3.5221)	−0.3013* (−1.6532)	−0.1456** (−1.8228)	−1.7436*** (−3.5287)	−0.2894* (−1.7780)
lnTAF	−0.0673*** (−6.6300)	−0.0045*** (−3.3021)	−0.0646*** (−5.9744)	−0.0676*** (−6.6423)	−0.0070 (−0.4733)	−0.0646*** (−6.0085)
lnGDP	0.8628*** (3.6300)	−1.2432*** (−1.9800)	0.9575*** (3.8133)	1.1141*** (4.3734)	−1.2152** (−1.8130)	1.0160*** (4.0300)
$\ln^2$GDP	−0.02257*** (−1.9639)	0.0362 (1.1882)	−0.0326*** (−2.5419)	−0.0298*** (−2.3735)	0.0343 (1.0555)	−0.0350*** (−2.7128)
lnFDI	−0.0554*** (−4.7362)	0.0963*** (4.8693)	−0.0631*** (−5.4514)	−0.0491*** (−4.1026)	0.1078*** (5.4350)	−0.0619*** (−5.3279)
lnIS	0.1332*** (2.6214)	1.0116*** (13.0533)	0.1694*** (2.2876)	0.1054** (1.9947)	1.0103*** (13.2658)	0.1654** (2.2336)
lnER	0.0539*** (3.0548)	0.5810*** (19.4350)	0.0507*** (2.8122)	0.0484*** (2.6768)	0.5700*** (19.4347)	0.0500*** (2.7668)
lnEC	0.0040 (0.8946)	0.3485*** (9.3206)	0.0742*** (3.2144)	0.0047 (0.8337)	0.3584*** (9.1785)	0.0771*** (3.3090)
ρ/ λ	0.2350*** (4.7718)	0.1369*** (3.6445)	0.0880* (1.6352)	0.2190*** (3.8695)	0.1650** (2.8323)	0.0640** (1.9506)
Adjusted R^2	0.8179	0.7344	0.2275	0.8017	0.7304	0.2253
Log-likelihood	309.5497	−229.0799	323.9462	304.1051	−231.6084	323.3858

Note: ***, ** and * indicate the significance at 1 %, 5 %, and 10 % levels, respectively. The values in brackets represent t statistics.

consists of employment flow, predominantly comprising low-skilled migrant workers and regular labor flow, with an additional influx of high-level and high-tech talents. Migrant workers and laborers with limited knowledge migrate from the central and western regions to the economically developed eastern regions, leading to a partial reduction in population density in the central and western regions. This, in turn, decreases the demand and consumption of living resources and energy, thereby mitigating the generation of domestic waste [56]. However, the influx of labor in the eastern region increases housing and transportation demands and consumption, promoting regional economic growth while intensifying carbon emissions early [57]. However, rapid socioeconomic development would entail decreasing the scale of China's labor flow [4]. In addition, with the development of the manufacturing industry in developed coastal areas, the proportion of labor-intensive industries gradually decreases. In general, the impact of labor mobility on carbon emissions is not significant. This research conclusion is consistent with the research of Li and Ma (2017) and Sun et al. (2021).

Capital flow will help reduce carbon emissions in the process of industrial transfer. As shown in Table 4, the estimated coefficients of lnCAF in the SLM model were −0.1788, −1.7202, and −0.3013, while the estimated coefficients in the SEM model were −0.1456, −1.7436, and −0.2894, passing the significance test at the 10 % level. The results indicate that capital flow has a significant impact on carbon emissions in the process of industrial transfer. The estimated coefficient is negative, indicating that capital flow has a restraining effect on regional carbon emissions and that capital flow between regions is conducive to carbon control. Capital flow between regions can often result in technology diffusion and resource accumulation, which, to a certain extent, promotes economic development [6]. Industrial transfer, characterized by capital agglomeration, is often dominated by high-tech and advanced industries. These industries not only bring new technologies to the region and promote economic development but also alleviate the regional environmental pressure, achieving a win-win situation of economic growth and environmental protection [23]. And with the widening economic development imbalance between the eastern, central, and western regions, capital flows between China's provinces have become more frequent. This cross-regional capital flow promotes economic development and improves the environment to a certain extent [25].This conclusion supports the research perspectives of scholars such as Chen et al. (2017) and Liu et al. (2020).

Moreover, technology flow can help reduce carbon emissions in the process of industrial transfer. As shown in Table 4, the estimated coefficients of lnTAF in the SLM model were −0.0673, −0.0045, and −0.0646, significant at the 1 % level; for the SEM model, the estimated coefficients were −0.0676, −0.0070, and −0.0646, significant and negative except for one (−0.0070). The results suggest a significant negative correlation between technology flow and carbon emissions and that technology flow between regions is conducive to carbon reduction. The conclusion is consistent with the research findings of scholars such as Ka et al. (2020) and Chen et al. (2019).To some extent, technology flow reflects technology diffusion and technology spillover, especially in the context of low-carbon emission reduction technology flow. Low-carbon technology flow generates clean technology and reduces energy consumption, providing enterprises with low-carbon and energy-saving production technology, processes, and research and development of low-carbon products. This type of technology flow can often lead to more effective energy conservation and emission reduction [58]. China has vigorously promoted clean technology projects in carbon emission control and actively introduced foreign low-carbon technologies and advanced low-carbon production processes [59]. At the same time, enterprises are encouraged to carry out low-carbon technological innovation and exchange to promote energy conservation and emission reduction practices.

4.3. Analysis of regional differences

To delve deeper into the regional variations in the influence of industrial transfers on carbon emissions and to verify the solidity of the empirical outcomes, an analysis of regional impact differences was conducted utilizing the SLM. The estimated consequences of industrial transfers on carbon emissions in the eastern, central, and western regions of the country are presented in Tables 5–7 respectively.

(1) Eastern region. The estimated results of the TFE model in Table 5 suggest that labor flow, capital flow, and technology flow in the eastern region are beneficial in reducing carbon emissions, which means that industrial transfer in the eastern region can help achieve carbon neutrality goals. Since the eastern region is the most economically developed in China, industrial transfer in this part mainly involves the emigration of high-polluting and energy-consuming industries into the central and western

Table 5
Results of the impact of industrial transfer on carbon emissions in the eastern region.

Variables	SFE		TFE		STFE	
	Coef.	t-value	Coef.	t-value	Coef.	t-value
lnLAF	1.0072	1.0897	−6.0033	−2.2020	0.4192	0.4061
lnCAF	1.2733	4.0721	−2.8710	−3.3784	0.9352	2.7018
lnTAF	−0.0050	−0.2573	−0.1062	−2.9882	0.0091	0.4033
lnGDP	4.4068	10.2100	4.1096	3.3053	4.5556	10.3480
$\ln^2$GDP	−0.1836	−8.9450	−0.2326	−3.9978	−0.1853	−8.9861
lnFDI	−0.1350	−5.3442	0.1528	2.7135	−0.1343	−5.2994
lnIS	−0.2700	−3.0293	1.2204	13.9076	−0.3340	−2.8065
lnER	−0.0029	−0.1304	0.3437	7.8347	−0.0067	−0.2964
lnEC	0.0040	0.6913	0.1543	2.4580	0.0117	0.4034
ρ	0.0480	0.8651	0.0650	1.7712	0.0130	2.2056
Adjusted R^2	0.8661		0.8805		0.5651	

Table 6
Results of the impact of industrial transfer on carbon emissions in the central region.

Variables	SFE		TFE		STFE	
	Coef.	t-value	Coef.	t-value	Coef.	t-value
lnLAF	0.0008	0.0390	−0.0013	−0.0164	0.0006	0.0323
lnCAF	0.1091	0.5594	2.9334	3.2086	0.3035	1.1930
lnTAF	0.0105	0.6813	0.1230	3.0106	0.0100	0.6767
lnGDP	4.4122	9.1527	−3.7990	−1.5478	4.5348	5.9332
ln^2GDP	−0.1975	−8.2875	0.0537	0.4516	−0.2228	−6.4474
lnFDI	0.0078	0.4848	0.0269	0.6397	−0.0006	−0.0389
lnIS	0.0306	0.6385	1.9795	8.2850	0.2166	2.5378
lnER	−0.0429	−1.9359	0.1992	2.7696	−0.0577	−2.7082
lnEC	0.0007	0.1506	0.9888	11.6359	0.1761	4.0144
ρ	−0.2360	−3.1687	−0.2360	−3.5995	−0.2360	−3.2330
Adjusted R^2	0.9094		0.6503		0.3795	

Table 7
Results of the impact of industrial transfer on carbon emissions in the central region.

Variables	SFE		TFE		STFE	
	Coef.	t-value	Coef.	t-value	Coef.	t-value
lnLAF	2.5856	1.7350	−4.4278	−1.3920	0.4929	0.3823
lnCAF	−0.5876	−1.9277	−0.0606	−0.0907	−0.1159	−0.4142
lnTAF	−0.0787	−5.2604	0.0350	1.6823	−0.0118	−0.7529
lnGDP	0.0851	0.1603	−4.6216	−2.9889	−3.1588	−4.5435
ln^2GDP	0.0215	0.7944	0.1985	2.5018	0.1383	4.0360
lnFDI	−0.0358	−1.9263	0.0799	3.0470	−0.0309	−2.0387
lnIS	0.3345	3.3910	0.3266	0.9392	0.3496	2.2750
lnER	0.1636	4.4498	0.6293	12.2988	0.1303	4.3377
lnEC	0.0088	0.9282	0.4869	7.5337	0.1049	2.4693
ρ	−0.2361	−2.5856	−0.2361	−3.1986	−0.2360	−2.6354
Adjusted R^2	0.8438		0.7472		0.3274	

regions, directly reducing its carbon emission levels to a certain extent. The labor flow into the eastern region has also gradually shifted from low-value to high-knowledge and high-technology and has gradually become mainstream, helping the eastern region increase labor productivity [60]. Moreover, in recent years, the eastern region has experienced a significant increase in foreign investment. This influx of foreign capital has not only brought financial resources but also a certain degree of technological transfer. As depicted in Fig. 4, the average level of foreign direct investment (FDI) in the eastern region far exceeds that of the central and western regions, and even surpasses the national average. This has led to a transformation of the region's industries, transitioning from labor-intensive to capital and technology-intensive, and from energy-intensive to smart, low-energy manufacturing and low-carbon outputs. This shift is conducive to the region achieving its emission reduction goals.

(2) Central region. The central region, as denoted in Table 6 (SFE model), demonstrates an estimated coefficient of 0.0008 for labor flow, 0.1091 for capital flow, and 0.0105 for technology flow. However, none of these figures are statistically significant. These findings indicate that although the transfer of industries in the central region elevates carbon emissions, the impact is not statistically significant. This can primarily be attributed to a few key factors. Predominantly, the industrial transferring process in China primarily involves the migration of high-polluting and energy-intensive industries from the eastern to the western region, with a significant emphasis on the central region. This, to a degree, elucidates the "pollution paradise" phenomenon observed in the central region. The relocation of outdated, energy-intensive, and high-polluting industries from the eastern region to the central region results in a surge in carbon emissions in the latter [61]. The eastern region's geographical, financial, and environmental superiority results in the central region's inability to compete when it comes to attracting advanced technology and capital inflows (refer to Fig. 5). Despite the central region's economic development being bolstered by capital and technology inflows, it falls short of achieving a balance between economic growth and carbon emission control [62].

(3) Western region. In the Western region, as depicted by the SFE model in Table 7, labor flow, capital flow, and technology flow have estimated coefficients of 2.5856, −0.5876, and −0.0787 respectively, all significant at the 10 % level. This suggests that the labor flow in the western region augments regional carbon emissions, while the flows of capital and technology are beneficial for diminishing carbon emissions. The increase in carbon emissions in the western region, triggered by labor migration, may be attributed to the government's recent promotion of the western development strategy. This strategy, aimed at attracting capital projects and investments to the region through policy incentives and tax benefits, has led to the relocation of labor-intensive industries to the western region, consequently escalating pollution levels [63]. However, the influx of capital

and technology has catalyzed economic growth in the western region and enhanced its energy consumption patterns, aiding in the achievement of both economic growth and environmental safeguarding goals.

4.4. Analysis of period heterogeneity

To reduce the environmental pollution caused by industrial transfer and guide the practice of industrial transfer in different regions more effectively, China's State Council officially issued the *Guiding Opinions of the State Council on the Undertaking of Industrial Transfer in the Central and Western Regions* on September 6, 2010; all regions carried out industrial transfer according to this guiding opinion [18]. Therefore, this study used 2010 as the dividing point to compare the effects of industrial transfer on carbon emissions for the two periods (i.e., 2003–2010 and 2011–2019).

Table 8 reports the impact of industrial transfer on carbon emissions for different periods. For 2003–2010, labor flow and technology flow helped reduce carbon emissions, while capital flow had no significant impact on carbon emissions. For 2011–2019, the impact of labor flow on carbon emissions was not significant, while capital flow and technology flow significantly reduced carbon emissions. The results suggest significant differences between labor flow and capital flow on carbon emissions at different time stages. Over time, the impact of labor flow on carbon emissions changed from significant to insignificant, while the impact of capital flow on carbon emissions switched from insignificant to significant. This indicates that with time, the environmental impact of capital and technology flows increases while the impact of labor flow on the environment declines. Industrial transfer, dominated by capital and technology flows, mainly involves technology-intensive and capital-intensive industries, which is conducive to improving the energy consumption mode of the industrial transfer area [18]. This helps develop a low-carbon economy and reduce carbon emissions while promoting economic growth.

5. Conclusions

This study systematically analyzed the carbon reduction effects of industrial transfer based on the perspective of factor flow and examined their relationship using spatial econometric models and Chinese provincial data from 2003 to 2019. The main findings are as follows.

(1) Industrial transfer significantly impacts carbon emissions, but different factor flows have different carbon reduction effects from the perspective of factor flow. Generally speaking, the movement of capital and technology is beneficial in diminishing carbon emissions. However, the inflow of labor does not demonstrate a significant influence on carbon emissions.
(2) Considering factor flow, the effect of industrial relocation on carbon emissions exhibits substantial regional variations. In the eastern region, the influx of labor, capital, and technology all contribute to a reduction in carbon emissions. However, in the central region, these three factors do not significantly affect carbon emissions. In contrast, the western region experiences an increase in carbon emissions due to labor inflow, while the inflow of capital and technology aids in carbon emission reduction.
(3) The impact of industrial transfer on carbon emissions has significant temporal differences from the perspective of factor flow. Over time, the environmental impact of capital and technology flows increases, while the impact on the environment of labor flow gradually declines.

Table 8
Time-regressive regression results.

Variables	2003–2010 years			2011–2019 years		
	SFE	TFE	STFE	SFE	TFE	STFE
lnLAP	−1.9413*** (−3.0182)	−3.4808* (−1.7366)	−2.0243*** (−3.1988)	0.0047 (0.1669)	0.0023 (0.0190)	0.0042 (0.1482)
lnCAP	0.1442 (0.6084)	−0.5255 (−0.9858)	0.0046 (0.0190)	−0.3582** (−1.9972)	−5.3341*** (−6.3338)	−0.1033** (2.3188)
lnTAP	−0.0472*** (−3.5187)	0.0314** (1.9805)	−0.0372*** (−2.8394)	−0.0315** (−1.4379)	−0.0492** (−2.4989)	−0.0406** (−2.9598)
lnGDP	0.0343 (0.1016)	−2.7993*** (−2.9812)	0.1775 (0.5236)	1.8309** (2.3437)	−0.9650 (−0.3975)	2.2564* (2.7881)
$\ln^2$GDP	0.0208 (1.2233)	0.1062** (2.2127)	0.0125 (0.6990)	−0.0793** (−2.2132)	0.0269 (0.2415)	−0.1056* (−2.7934)
lnFDI	−0.0091* (−1.6951)	0.1116*** (3.8109)	−0.0225 (−1.2499)	−0.0116 (−0.8159)	0.1202*** (4.7496)	−0.0053** (−2.3707)
lnIS	0.2400*** (2.8191)	0.9254*** (8.9569)	0.1840** (2.0443)	0.0095 (0.1723)	1.0394*** (9.9162)	0.0566 (0.6164)
lnER	0.0688*** (2.8796)	0.7504*** (18.0845)	0.0787*** (3.2353)	−0.0044 (−0.2448)	0.4384*** (11.2293)	−0.0066*** (−3.3670)
lnEC	0.1487** (2.2766)	0.4901*** (8.8986)	0.0733 (1.1126)	0.0091*** (2.6029)	0.3367*** (7.0677)	0.0129 (0.6990)
ρ/ λ	0.0260* (1.7468)	0.0870* (1.8481)	−0.22780** (−2.6195)	0.0830* (1.7154)	0.0710 (1.3232)	0.0460** (1.9548)
Adjusted R^2	0.8659	0.8388	0.2583	0.6841	0.7176	0.5660

Note: ***, ** and * indicate the significance at 1 %, 5 %, and 10 % levels, respectively. The values in brackets represent t statistics.

Based on the conclusions of the above research and in the light of China's actual situation, the following recommendations are put forward: First, formulate policies to guide the transfer of capital and technology to the environmental protection industry. Encourage the transfer of capital and technology to the field of environmental protection industry to improve the application level of environmental protection technology and industrial development in order to reduce carbon emissions. The government can attract capital and technology to invest in the environmental protection field through tax concessions, subsidies and other incentives. Second, strengthen labor force training and resettlement. In response to the increase in carbon emissions due to the inflow of labor in the western region, the government should strengthen the training and resettlement of the labor force. Through training, the government should enhance the skill level of the labor force to help them better adapt to the needs of the environmental protection industry and reduce carbon emissions. Third, regional differentiated carbon emission policy. Regional differentiated carbon emission policies should be formulated according to the factor flow situation and carbon emission in different regions. For regions with different impacts of labor, capital and technology inflows on carbon emissions, corresponding policy measures can be taken to promote carbon emission reduction and environmental protection industry development. The above policy recommendations aim to make full use of the flows of capital, technology and labor to promote carbon emission reduction and the development of environmental protection industries, and to achieve the goal of sustainable development.

Limitations

This study has set out to explore the impact of industrial transfer on carbon emissions through an analysis of factor flow, aiming to provide a more comprehensive understanding of the process of industrial transfer and its implications for carbon emissions. However, there are still some shortcomings in this study that need to be addressed. Firstly, the measurement of factor mobility is a complex task with various indicators available, each with its own advantages and disadvantages. While this study has made efforts to incorporate the strengths of existing measurement methods and mitigate their limitations, the intricate nature of industrial specialization poses challenges in accurately assessing the impact of factor mobility on carbon emissions. Future research could benefit from utilizing advanced tools such as big data and modern technology to measure factor mobility and industrial transfer more precisely and objectively. Furthermore, while this study has focused on key factors such as economic development, industrial structure, and environmental regulations in examining industrial transfer and carbon emissions, it is important to acknowledge that there are numerous other factors at play. Future research should consider the comprehensive impact of trade, the international environment, and other relevant factors from both global and domestic perspectives for a more holistic understanding of the issue.

Institutional ethics committee provided approval

Approval from the institutional ethics committee was not obtained.

Data availability statement

The paper data used to support the findings of this study have been deposited in the [https://pan.baidu.com/s/1Z51EzG1WESMqziNk8NlMsw (79ed)].

CRediT authorship contribution statement

Guohua Niu: Visualization, Investigation, Conceptualization. **Yuanhua Yang:** Writing – original draft, Visualization, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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