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Regional Industrial Redistribution and Carbon Emissions: A Dynamic Analysis for China

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Abstract
To facilitate and balance regional economic development and to reduce carbon emissions, China has implemented a series of policies to promote the redistribution of industries and economic activities across regions since 2000.[1] This paper employs a logarithmic mean Divisia index (LMDI) to analyse the dynamic net effect on carbon emissions of Chinese policies promoting economic redistribution across sub-national regions, using a panel data of five sectors in 30 provinces during 1995–2017. The results of our analysis show that the redistribution of industry in particular, but also business and construction activities, leads to an increase in CO_2 emissions, while the relocation of agriculture and transportation activities reduces emissions. We also find that the emission increase effect of the transfer of carbon intensive industries to new (host) regions is higher than the emission reduction effect induced by the agglomeration of clean industries in the original (home) regions. However, from 2014–2017, alongside the gradual industrial redistribution, China has also reduced aggregate CO_2 emissions by 58.6 MT. In addition, the results show that population migration, which is due to redistribution of industry and other economic activity, has caused higher emission increases than emission reductions due to redistribution policies. We further calculate the marginal effect of industrial redistribution on CO_2 emissions and draw out relevant policy implications.

Key policy insights:

- Industrial (and other economic activity) redistribution within a county can be not only an economic policy, but also an important policy instrument to mitigate CO_2 emissions. This is the case in China.
- In the process of regional industrial redistribution, policymakers should aim to reduce the emission increase effect of transfer of carbon-intensive industries to host regions and to raise the emission reduction effect induced by an agglomeration of clean industries in home regions.
- Industrial redistribution is usually a long-term strategy for regional development within a county, and any reduction effects on CO_2 emissions are likely to need time to appear.

Key words: Industrial redistribution; regional development and climate; population migration; CO_2 emissions

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[1] This paper uses the term "industrial redistribution" broadly to refer to policies targeting the redistribution of industrial activities as well as the redistribution of other economic activities (specifically agriculture, business, construction, transportation).

1. Introduction

When faced with stringent environmental regulations, firms in polluting industries are highly likely to shift to places with lax environment policies. Copeland and Taylor (2004) calls this as the "Pollution Haven Effect" (PHE). The movement, or "transfer of industries," is usually accompanied by the transfer of pollution, which has long been an issue of concern for policymakers. Most existing literature focuses on examining the transfer of pollution among countries (Baumol & Oates, 1988; Chichilnisky, 1994; Copeland & Taylor, 1994). By contrast, the transfer of pollution within a country has not received as much attention. Some studies investigate the pollution reduction mandates and firm location choice in China, finding that regulation reduces pollution-intensive activity in highly-regulated areas but increases it in less stringent locations (Cai et al., 2016; Chen et al., 2018; Duvivier and Xiong, 2013; Wu et al., 2017). The extent to which the pollution increases in lax regulation areas and decreases in more stringently-regulated locations due to industrial transfer in a large country like China has not been fully explored in the literature. Unlike industrial transfer across country boundaries, industrial and economic activity redistribution within a country is usually associated with the nation's long-term development strategy and is thus worthy of research.

China has a regional economic development policy with a proposed strategy of "development of the West region" from 2000, aiming to balance the economic development across regions. Since then, China has carried out a series of industrial transfer policies to promote regional economic development and optimise regional industry distribution. In 2010, the China State Council issued a document named "Guidelines for Central and West Regions Undertaking Transferred Industries." Then the Ministry of Industry and Information Technology issued "Guidance Directory for Industry Transfer (2012)"[2] and "Guidance Directory for Industry Transfer (2018)."[3] Over the years, the transfer of industries from one region to another has shown a "flying geese" pattern with industries relocating from the East to the Central and West regions of China. For example, Ruan and Zhang (2014) find that the textile and apparel industry was clustered in the East region of China before around 2005, but it has since shifted toward the Central and West regions. In the same period, the

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[2] This document can be retrieved from "http://www.gov.cn/gzdt/att/att/site1/20120803/70f3950952e411857fe101.pdf"
[3] This document can be retrieved from "https://wap.miit.gov.cn/cms_files/filemanager/oldfile/miit/n1146285/n1146352/n3054355/n3057254/n7600006/c7600329/part/7600335.pdf"

agricultural sector shifted from the East to Northeast and West regions, but business by comparison tends to agglomerate in the East.

This study explores how this industry and economic activity location transfer and agglomeration affects carbon emissions. We study five main sectors, namely agriculture, industry, construction, business and transportation, and the household sector.[4] The literature on the relationship between industrial agglomeration and carbon emissions is limited. One exception is Qin and Wu (2014), which finds that the intensity of CO_2 emissions first goes up and then goes down as the degree of urban concentration increases. Some studies investigate the relationship between agglomeration and environmental pollution, but show conflicting results. Some show that agglomeration leads to the expansion of production and thus increases pollution (De Leeuw et al., 2001; Duc et al., 2007; Li et al., 2021; Verhoef and Nijkamp, 2002; Virkanen, 1998). While Zeng and Zhao (2009) find that the agglomeration of manufacturing can alleviate the 'Pollution Haven' effects of foreign direct investment (FDI), Fang et al. (2020) find that economies of scale and technology improvement brought by agglomeration reduces pollution. In addition, some research finds a nonlinear relationship between agglomeration and environmental pollution (Wang and Wang, 2019; Yuan et al., 2020). However, industrial agglomeration exerts different effects on different industries and different regions. It is necessary to take into account the agglomeration effect when evaluating the environmental impact of industrial transfer and regional development policies.

The main objective of this paper is therefore to extend existing studies by exploring the industrial agglomeration effect on CO_2 emissions in the East region of China and, in particular to explore the linkages to cleaner industrial development following the transfer or change in location of industries or other economic activities. This study contributes to the literature in the following ways. Firstly, we gauge the dynamic net effects and marginal effects of industrial and economic sectoral redistribution on CO_2 emissions in China. By doing this we extend methods to investigate

[4] We use the terms "industrial redistribution" and "transfer of industries" broadly to refer to redistribution or transfer of these five main sectors (agriculture, industry, construction, business and transportation). The categories of our sectors are based on China Energy Statistical Yearbook. The agriculture sector includes agriculture, forestry, animal husbandry, and fishery. The industry sector includes mining, manufacturing, production and supply of electricity, heat, gas, and water. The construction sector refers to construction, installation, and decoration for housing, all buildings and other built infrastructure. The business sector includes wholesale and retail trades, hotels and catering services, and other services. The transportation sector includes transportation, storage, and postal and courier activities.

the relationship between industrial and other economic activity transfer, industrial and technological agglomeration, and CO_2 emissions. The previous literature ignores the importance of heterogeneity in industries' regional distribution on CO_2 emissions (e.g. Zheng et al., 2019). Secondly, we study both the emission increase effects of industrial transfer and agglomeration effects of clean industries in reducing CO_2 emissions, while existing studies focus only on one aspect or the other. Considering both effects is important for the evaluation of the combined impact of industrial transfer strategies and policies on pollution, and specifically on CO_2 emissions. Thirdly, we further investigate the effects of population migration, which is induced through industrial redistribution, on CO_2 emissions. Finally, we examine the effect of industrial transfer on emissions within a country rather than across country boundaries. As a large developing country experiencing decadal, long-term growth, China provides a perfect case to explore this issue. This case study sheds light on other developing countries with similar industrial transfer and regional development strategies.

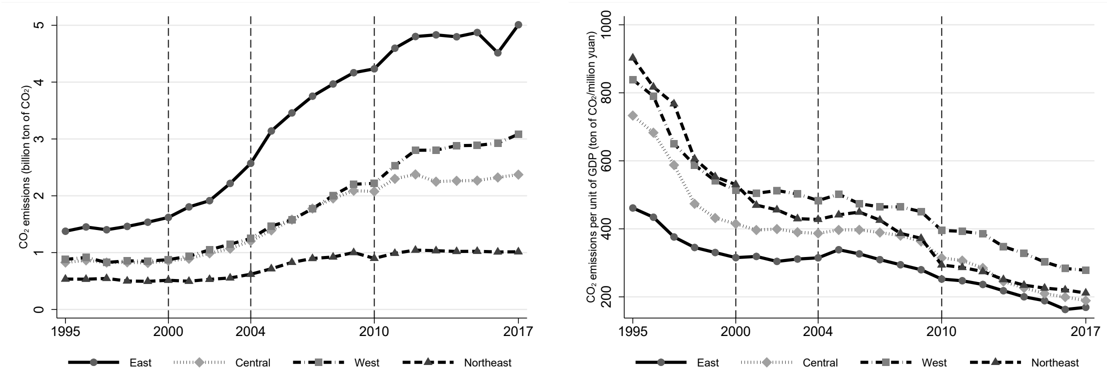
The remainder of the paper is organised as follows. Section 2 background and then Section 3 presents the methodology and data. Section 4 presents the empirical results, and this is followed by a further analysis and discussion (Section 5). The overall conclusion and policy implications are set out in Section 6.

2. Background

Carbon emissions in China have not necessarily been tracked with regional transfers of industry and other sectors. As shown in Figure 1(a), with the implementation of industrial transfer policies in China (since 2000), a regional analysis shows the East has not shown any decrease in CO_2 emissions compared with the Central and West regions in the period 1995-2017.[5] One possible reason is that the environmental problems in the East are not reduced through industrial transfer, because some industries in the East tend to move to places nearby so as to maintain the market. Another potential reason is that, compared with industries in the Central and the West regions, the transferred

[5] Given the data availability, this study includes 30 provinces, excluding Tibet, Hong Kong, Macau and Taiwan. Based on the National Bureau of Statistics in China, we divide these 30 provinces into four regions, namely, the East, the Central, the West, and the Northeast region. The East region includes 10 provinces/municipalities, namely Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The Central region includes 6 provinces, namely Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The West region includes 11 provinces/municipalities, namely Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The Northeast region includes three provinces, namely Liaoning, Jilin and Heilongjiang.

industries and other sectors from the East embed with advanced technology, which help the new host regions (e.g. the Central and West) improve their environmental performance.



(a) (b)

Figure 1. Trends of regional CO_2 emissions in China.

Note: The CO_2 emissions are calculated using data from five production sectors (i.e. agriculture, industry, construction, business and transportation) and the household sector in 30 provinces. The East region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The Central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The West region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The Northeast region includes Liaoning, Jilin and Heilongjiang.

Figure 1(b) shows that the CO_2 emissions per GDP decreases with industrial redistribution and gradual convergence occurs across the four regions in China. This is because when the carbon-intensive industries transferred out of the East, the East then upgraded technology and developed cleaner industries, which leads to a reduction in CO_2 emissions per GDP. Therefore, only considering the emission increase effects of industry transfer might be inadequate to evaluate the effect of industrial redistribution on CO_2 emissions within a country.

3. Methodology and data

We employ the method of logarithmic mean Divisia index (LMDI) to analyse the dynamic net effect on carbon emissions of Chinese policies promoting industrial redistribution across sub-national regions. We use a panel data of five sectors in 30 provinces during 1995–2017.

3.1 Measurements of industrial distribution

To make things simple, in this section and section 3.2, we refer to industry and other sectors under the simple term "industry". The share of industrial output is widely used in measuring industrial distribution (Wen, 2004). Therefore, our first indicator is industry share:

$$ER_{pi} = \frac{Y_{pi}}{Y_i} \quad (1)$$

where Y_{pi} is output of sector i in province p; Y_i is total output of sector i; ER_{pi} is share of output, and its change reflects changes of industrial distribution of sector i in province p among provinces. Obviously, the change of ER_{pi} is affected by scale and structure, therefore, this is a simplified measurement. The scale effect refers to the change of all industries' share of output due to the change in the region's total output; the structure effect reflects the change of industries' share of output induced by change of industrial distribution under constant scale, which also results in structural change in the region. To measure industrial distribution in detail, we further decompose ER_{pi} into industry location quotient and share of output, then Equation (1) becomes:

$$ER_{pi} = \frac{Y_{pi}/Y_i}{Y_p/Y} \times \frac{Y_p}{Y} = LQE_{pi} \times ER_p \quad (2)$$

where Y_p is total output in province p; Y is the national output; LQE_{pi} refers to location quotient of sector i in province p, and its changes indicate structure changes of industrial distribution. This measurement is popularly used to measure industrial transfer in the literature (Hoover, 1936). ER_p refers to the share of output in province p, and its changes reflect scale variation.

Similar to measures of industrial distribution, we construct share of population for urban and rural areas PR_{pi}, and decompose it to location quotient LQP_{pi} and share of population PR_p:

$$PR_{pi} = \frac{P_{pi}}{P_i} = \frac{P_{pi}/P_i}{P_p/P} \times \frac{P_p}{P} = LQP_{pi} \times PR_p \quad (3)$$

Where P_{pi} is urban or rural population in province p; P_i is urban or rural population; P_p is total population in province p; P is the national population; PR_{pi} is share of population, and its change reflects changes of urban or rural population distribution in province p; LQP_{pi} is location quotient, and its changes indicate structure changes of urban or rural population in province p; PR_p is share of population in province p, and its change reflects population distribution changes.

3.2 LMDI method

Most Index Decomposition Analysis (IDA) methods neglect the direct and indirect effects of regional structure on emissions, while Structural Decomposition Analysis (SDA) methods explain the impact of various drivers only from the perspective of demand. For this reason, we follow Zheng et al. (2019) to employ the method of Logarithmic Mean Divisia Index (LMDI) to perform our analysis. This method is preferable for its path independence, aggregation consistency and ability to handle zero values (Zheng et al., 2019), and has been widely used in the literature (Xia et al., 2021). Another advantage of this method is that it can include more than one factor that affects carbon emissions and estimate their effects on the basis of year-province-sector. Econometric models, however, cannot decompose the contribution of each component on carbon emissions, but instead help estimate the average effect of each component on carbon emissions (Auffhammer & Carson, 2008; Zheng et al., 2019). We extend the LMDI method to explore the dynamic net effect of industry distribution on carbon emissions by controlling energy structure, technology, industrial structure, urban and rural population structure, and scale of the economy and of the population.

Based on Kaya identity (Kaya, 1989), we decompose the CO_2 emissions of the five sectors (i.e. agriculture, industry, construction, business and transportation) and the urban and rural population into the product of several factors that affect CO_2 emissions, and then employ Divisia Index based on LMDI to analyse the dynamic net effect of each factor. To be specific, we divide CO_2 emissions into emissions from production sector (i=1, …, 5, refers to agriculture, industry, construction, business, and transportation, respectively) and emissions from household consumption (i=6, 7, refers to urban and rural population, respectively), and set up the following model:

$$
\begin{aligned}
C &= \sum_{p=1}^{30}\sum_{i=1}^{7} C_{pi} = \sum_{p=1}^{30}\sum_{i=1}^{5} \frac{C_{pi}}{E_{pi}}\frac{E_{pi}}{Y_{pi}}\frac{Y_{pi}}{Y_i}\frac{Y_i}{Y}Y + \sum_{p=1}^{30}\sum_{i=6}^{7} \frac{C_{pi}}{E_{pi}}\frac{E_{pi}}{P_{pi}}\frac{P_{pi}}{P_i}\frac{P_i}{P}P \\
&= \sum_{p=1}^{30}\sum_{i=1}^{5} CD_{pi}EIY_{pi}ER_{pi}ES_iY + \sum_{p=1}^{30}\sum_{i=6}^{7} CD_{pi}EIP_{pi}PR_{pi}PS_iP
\end{aligned} \tag{4}
$$

where C is the national CO_2 emissions; C_{pi} is the CO_2 emissions of sector i in province p; E_{pi} is the energy consumption of sector i in province p; $CD_{pi} = C_{pi} / E_{pi}$ is carbon intensity of sector i in province p; $EIY_{pi} = E_{pi} / Y_{pi}$ is energy intensity of sector i in province p; $ES_i = Y_i / Y$ is industrial structure of sector i; $EIP_{pi} = E_{pi} / P_{pi}$ is urban or rural per capita household carbon emissions in province p; $PS_i = P_i / P$ is urban or rural population structure of sector i.

Hence, the change in national CO_2 emissions ($\Delta\ C^t$) in year t compared with year t–1 is estimated as:

$$
\begin{aligned}
\Delta C^{t} &= \sum_{p=1}^{30}\sum_{i=1}^{7} L(C_{pi}^{t}, C_{pi}^{t-1}) \ln\frac{CD_{pi}^{t}}{CD_{pi}^{t-1}} \\
&+ \sum_{p=1}^{30}\sum_{i=1}^{5} L(C_{pi}^{t}, C_{pi}^{t-1})(\ln\frac{EIY_{pi}^{t}}{EIY_{pi}^{t-1}} + \ln\frac{ER_{pi}^{t}}{ER_{pi}^{t-1}} + \ln\frac{ES_{i}^{t}}{ES_{i}^{t-1}} + \ln\frac{Y^{t}}{Y^{t-1}}) \\
&+ \sum_{p=1}^{30}\sum_{i=6}^{7} L(C_{pi}^{t}, C_{pi}^{t-1})(\ln\frac{EIP_{pi}^{t}}{EIP_{pi}^{t-1}} + \ln\frac{PR_{pi}^{t}}{PR_{pi}^{t-1}} + \ln\frac{PS_{i}^{t}}{PS_{i}^{t-1}} + \ln\frac{P^{t}}{P^{t-1}}) \\
&= \Delta C_{CD} + \Delta C_{EIY} + \Delta C_{ER} + \Delta C_{ES} + \Delta C_{Y} + \Delta C_{EIP} + \Delta C_{PR} + \Delta C_{PS} + \Delta C_{P}
\end{aligned} \tag{5}
$$

where

$$
L(C_{pi}^{t}, C_{pi}^{t-1}) = (C_{pi}^{t} - C_{pi}^{t-1}) / \ln(C_{pi}^{t} / C_{pi}^{t-1}) \tag{6}
$$

$L(C_{pi}^{t}, C_{pi}^{t-1})$ is a logarithmic mean value weight function. ΔC_{CD}, ΔC_{EIY}, ΔC_{ER}, ΔC_{ES}, ΔC_{Y}, ΔC_{EIP}, ΔC_{PR}, ΔC_{PS}, ΔC_{P} represents effects of carbon intensity, energy intensity in the sector, industrial distribution, industrial structure, size of the economy (scale), per capita carbon emissions, population distribution, urban and rural population structure, and size of the population (scale), respectively.

For these nine factors, the net effects of industrial and economic sectoral distribution ΔC_{ER} and population distribution ΔC_{PR} on CO_2 emissions are of particular interest of this study. Based on the measures of sectors and population distribution, share of output can be decomposed into a product of industry location quotient and total share of output; and share of population can be decomposed into product of urban or rural location quotient and total share of population. Take Equation (2) and (3) into Equation (5) respectively, we obtain:

$$
\Delta C_{ER} = \Delta C_{LQE} + \Delta C_{ERT} \tag{7}
$$

$$
\Delta C_{PR} = \Delta C_{LQP} + \Delta C_{PRT} \tag{8}
$$

where ΔC_{LQE} is structure effects of industrial distribution, which reflects changes of industrial distribution on CO_2 emissions under constant share of total output; ΔC_{ERT} is scale effect of industrial distribution, and it reflects change in share of output on CO_2 emissions; ΔC_{LQP} is structure effects of population distribution, and it reflects the distribution of urban (or rural) population on CO_2

emissions under constant of share of total population; and ΔC_{PRT} is scale effects of population distribution, and it reflects changes in share of population on CO_2 emissions.

The above constructed LMDI can reflect marginal effect of industry and population distribution on CO_2 emissions, which can further gauge dynamic marginal effect of industry and population distribution on CO_2 emissions. Specifically, let ΔC_{xp} be the additional increase in CO_2 emissions caused by changes in share of output (or population) in province *p*, and this can be calculated by LMDI, and let Δx_p be the changes of share of output (or population) in province *p*, then we obtain the marginal effect of industrial distribution (population distribution) on CO_2 emission as:

$$MC_{xp} = \Delta C_{xp} / \Delta x_p \quad (9)$$

3.3 Data

Given the data availability, this study includes 5 economic sectors (i.e. agriculture, industry, construction, business and transportation) and 2 household sectors (i.e. urban and rural population) in 30 provinces in China for the period of 1995 to 2017, excluding Tibet, Hong Kong, Macau and Taiwan. The agriculture sector refers to the production of agricultural products and includes crop, forestry, animal husbandry and fishery. The industry sector includes mining, manufacturing, production and supply of electricity, heat, gas and water. The construction sector refers to construction, installation and decoration for housing, all buildings and other built infrastructure. The business sector includes wholesale and retail trades, hotels and catering services, financial intermediation, real estate and other services. The transportation sector includes rail, pipeline, road, water and air transportation and associated activities such as terminal and parking facilities, cargo handling and storage, and this sector also includes postal and courier activities.

The main data sources are from *China Energy Statistical Yearbook* from 1991 to 2018, *China Compendium of Statistics* 1949–2008, *China Population and Employment Statistics Yearbook* from 1996 to 2010, *China Statistical Yearbook* from 2010 to 2018, and statistical yearbooks of provinces from 2012 to 2018. The details of how we measure energy and carbon emissions are provided in Appendix A of the Supplementary Materials (SM).

4. Empirical results

4.1 The effect of industrial redistribution

Figures S1 and S2 in the Supplementary Materials depict some trends and stylised facts about the relationship between industrial redistribution and CO_2 emissions. From the figures we can see that the unit output CO_2 emissions of the industry and transportation sectors are relatively high among the five sectors. As the major transferring sector, industry began to move from the East to the Central and West since 2004, while the agriculture sector shifted from the East to Northeast and West, and business sector tended to agglomerate in the East. As the supporting sector for transferring, transportation first stayed in the West and began to agglomerate in the East and Northeast starting in 2005, while construction tended to agglomerate in the West. We start analysing the dynamic net effect of industrial and economic sectoral redistribution on CO_2 emissions from the dimension of year and region.

4.1.1 The net effect by year

Based on the LMDI model constructed, we compute the dynamic net effect of changes in shares of output, industrial location quotient, and total shares of output on CO_2 emissions for the five sectors (agriculture, industry, construction, business and transportation) and 30 provinces, and obtain the total effect of industrial redistribution, the effect of structure change, and the effect of scale change for the five sectors. Table 1 provides the net effect of industry, agriculture and business sectors transfer on CO_2 emissions.

Overall, redistribution of the industry and business sectors leads to an increase in total CO_2 emissions. Especially in 2012, the net effect of industrial redistribution reached 36.17 Mt of CO_2. While the re-distribution of agriculture restrained CO_2 emissions, cumulatively decreasing 4.62 Mt of CO_2 during 1995–2017.

The carbon-intensive industry sector drives an increasing trend in CO_2 emissions since industries are transferring to the Central and the West regions in 2004, and this trend continues until 2014. The cumulative increase of CO_2 emissions from industry during 2005–2013 reaches 145.48 Mt of CO_2, of which 84.09 Mt of CO_2 is due to structural change effects and 61.40 Mt of CO_2 to scale change effects. Hence, the transfer of industry alone leads to an increase in CO_2 emissions.

As a low-carbon sector, the transfer of agriculture leads to significant emission reductions in most years. By comparison, the transfer of the business sector – also low carbon-intensity – results in an increase in carbon emission during our study period. But it shows a stable emission reduction effect since 2013, cumulatively decreasing CO_2 emissions by 2.28 Mt of CO_2 between 2013 and 2016. This reduction is mainly due to scale effect, i.e. the economy gradually moving to the Central and the West regions. This is consistent with the release of the document "Guidance Directory for Industry Transfer" in 2012 by the Ministry of Industry and Information Technology. However, with the change in structure of the economy, the transfer of the business sector increased CO_2 emissions by 0.65 Mt from 2016 to 2017.

Table 1: The net effect of redistribution of industry, agriculture and business sectors on national CO_2 emissions by year (Mt of CO_2)

Year	Industry			Agriculture			Business		
	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect
1996	–6.24	–4.24	–2.01	–0.19	–0.03	–0.15	–0.43	0.08	–0.51
1997	–4.77	0.06	–4.83	–1.37	–1.04	–0.33	–0.06	0.42	–0.48
1998	36.16	20.83	15.33	–0.02	–1.08	1.05	–1.12	1.01	–2.14
1999	–10.05	–5.44	–4.61	–2.56	–2.23	–0.33	–0.28	–0.52	0.24
2000	–7.53	–3.01	–4.51	0.63	0.92	–0.29	0.51	0.14	0.37
2001	–6.99	–5.65	–1.35	–0.75	–0.62	–0.13	0.68	0.34	0.35
2002	–9.21	–9.73	0.52	0.54	0.68	–0.13	0.19	0.16	0.03
2003	–14.40	–15.37	0.97	0.69	0.89	–0.20	–0.02	0.01	–0.03
2004	–4.13	–5.17	1.04	–0.37	–0.03	–0.34	0.66	0.65	0.01
2005	16.88	10.44	6.44	–0.85	–0.81	–0.04	0.60	0.73	–0.12
2006	7.99	10.27	–2.28	–0.56	–0.12	–0.44	0.85	1.26	–0.41
2007	10.58	12.71	–2.13	–0.31	–0.09	–0.22	1.01	0.67	0.33
2008	14.26	9.60	4.66	0.18	–0.11	0.30	1.19	2.28	–1.09
2009	9.56	2.49	7.07	–0.14	–0.44	0.31	–0.12	1.33	–1.45
2010	2.45	–0.02	2.47	0.06	–0.13	0.19	–0.53	0.23	–0.76
2011	27.78	8.33	19.45	0.44	–0.85	1.29	0.91	1.43	–0.52
2012	36.17	17.15	19.03	0.11	–0.97	1.07	0.09	0.83	–0.74
2013	19.81	13.12	6.68	0.28	–0.03	0.30	–0.70	–0.04	–0.66
2014	–6.62	–0.38	–6.24	0.12	0.22	–0.10	–0.81	0.04	–0.85
2015	–12.64	–5.70	–6.94	–0.55	–0.36	–0.20	–0.34	0.97	–1.31
2016	–15.56	–5.23	–10.34	0.07	0.30	–0.23	–0.43	0.07	–0.49
2017	–18.50	–9.43	–9.08	–0.08	0.63	–0.71	0.65	1.19	–0.54
Total	64.98	35.64	29.34	–4.62	–5.30	0.67	2.50	13.27	–10.77

Note: The results are from authors' calculations using the dataset.

Table 2 provides the net effect of the transfer of transportation and construction sector activities on CO_2 emissions during 1995 to 2017. Overall, the transfer of the construction sector raises CO_2 emissions, while that of transportation displays the opposite effect. As a carbon intensive sector, transportation's CO_2 emissions decreased by 1.79 Mt of CO_2 when agglomerating to the Central and the West regions during 1995–2004, and reduced by as much as 7.27 Mt of CO_2 when agglomerating to the East and the Northeast during 2005–2017. For construction, as a low-carbon emission sector (since emission-intensive materials are accounted for under industry), it moves towards the West during our 1995–2017 study period and reveals a continuous emission increase through scale effects since 2007, but emission reduction structures effect on CO_2 emissions since 2010.

Table 2: The net effect of transportation and construction redistribution on national CO_2 emissions by year (Mt of CO_2)

Year	Transportation			Construction		
	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect
1996	0.20	0.23	–0.02	–0.04	–0.04	0.00
1997	0.51	0.67	–0.16	0.34	0.37	–0.03
1998	–3.58	–3.86	0.28	1.77	1.43	0.34
1999	0.53	0.62	–0.09	0.35	0.43	–0.08
2000	0.80	0.74	0.06	0.20	0.24	–0.04
2001	–0.74	–0.72	–0.02	–0.05	–0.09	0.04
2002	1.50	1.51	–0.01	0.51	0.50	0.01
2003	0.33	0.53	–0.20	–0.53	–0.54	0.01
2004	–1.35	–0.97	–0.38	–0.66	–0.72	0.06
2005	–1.05	–0.87	–0.17	0.16	0.03	0.14
2006	–1.23	–0.76	–0.47	0.08	0.09	–0.01
2007	1.11	0.95	0.16	0.10	0.04	0.06
2008	0.59	0.66	–0.07	–0.37	–0.41	0.04
2009	–5.20	–4.44	–0.76	0.18	0.09	0.09
2010	0.40	0.39	0.01	0.01	–0.15	0.16
2011	0.80	0.56	0.23	–0.24	–0.75	0.51
2012	0.87	0.71	0.16	–0.21	–0.63	0.43
2013	0.22	0.33	–0.10	–0.06	–0.33	0.28
2014	–0.53	0.56	–1.09	–0.10	–0.29	0.19
2015	–0.70	0.59	–1.28	–0.09	–0.28	0.19

2016	–1.52	0.18	–1.70	0.14	–0.26	0.40
2017	–1.04	–0.75	–0.28	–0.10	–0.14	0.04
Total	–9.06	–3.14	–5.92	1.40	–1.42	2.82

Note: The results are from authors' calculations using the dataset.

4.1.2 The net effect by region

We calculate the average net effect of industrial redistribution on CO_2 emissions for all regions during 1995–2017.[6] The results are presented in Table 3 and 4 respectively.

According to Table 3, for the industry sector, on the one hand, the East reduces CO_2 emissions around 14.59 Mt of CO_2 every year due to industrial transfer. On the other hand, the Central and the West regions, on average, increase CO_2 emissions by 25.29 Mt of CO_2 per year on average due to the industries that are transferring into these regions in this period. With respect to the transfer of agriculture sector activities, the transfer leads to an average of 0.57 Mt of CO_2 reduction per year in CO_2 emissions in the East. The Northeast and the West increased CO_2 emissions, on average, by 0.46 Mt of CO_2 per year because of the transfer of agricultural activities. Unlike other sectors, the business sector moves towards the Central and West regions when measured by output shares, but when measured by location quotient, the East and the Northeast hold the largest share, which leads to opposing structure effects and scale effects. However, as the strength of scale effect is higher than that of the structure effect, the total redistribution effect of the business sector in the East and Northeast is consistent with the scale effect leading to a reduction in carbon emissions. Nevertheless, these effects are much lower than that of the industry sector for these regions; for example, the aggregate redistribution effect of business in the East is merely –0.11 Mt of CO_2 per year, which is negligible when considering its emission volume (496.61 Mt of CO_2 in 2017).

Table 3: The average annual net effect of industry, agriculture and business redistribution on CO_2 emissions by region (Mt of CO_2 per year), 1995–2017

Region	Industry			Agriculture			Business		
	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect
East	–14.59	–10.78	–3.80	–0.57	–0.49	–0.08	–0.11	1.04	–1.15
Central	11.02	7.85	3.17	–0.09	–0.29	0.20	0.17	–0.18	0.34

[6] We also calculate the average net effect of industrial redistribution on CO_2 emissions for provinces during 1995–2017, and the results are presented in the Table S2 and S3 in the Supplementary Materials.

West	14.27	7.48	6.79	0.32	0.20	0.12	0.34	–0.64	0.98
Northeast	–7.87	–3.00	–4.88	0.14	0.35	–0.21	–0.29	0.36	–0.64

Note: The results are from authors' calculations using the dataset.

Per results in Table 4, the Central and the West regions develop transportation and construction sectors, taking in industries from the East. The development of the transportation sector in the West leads to an increase of 0.28 Mt of CO_2 in CO_2 emissions per year. The CO_2 emissions in the Central and the West regions on average go up by 0.63 Mt of CO_2 annually due to the agglomeration of construction. It is worth noting that the industrial redistribution effect of transportation and construction in the East is –0.42 Mt of CO_2 and –0.55 Mt of CO_2 per year, respectively, declines that are much greater than the emission increase effects the transfer of these economic activities appear to exert on the Central and the West regions.

Table 4: The average net effect of transportation and construction redistribution on CO_2 emissions for regions (Mt of CO_2 per year), 1995–2017

Region	Transportation			Construction		
	Total effect	Structure effect	Scale effect	Total effect	Structure effect	Scale effect
East	–0.42	0.37	–0.79	–0.55	–0.48	–0.07
Central	0.02	–0.30	0.32	0.13	0.04	0.09
West	0.28	–0.51	0.79	0.50	0.34	0.16
Northeast	–0.27	0.31	–0.58	–0.02	0.04	–0.05

Note: The results are from authors' calculations using the dataset.

4.2 The comprehensive analysis of industrial and economic sectoral redistribution

Next, we focus on analysing which effect is dominant for the whole country and each region: the emission increase effect due to the transfer of high-carbon or carbon-intensive sectors, or the emission reduction effect because of the agglomeration of low-carbon intensive sectors? In addition, we explore how to further improve industrial redistribution given sectoral and regional characteristics of CO_2 emissions.

4.2.1 Total effect: reduction in carbon emissions or emissions transfer?

From the above analysis, we find that the Central and the West regions mainly play the role of taking industries transferred in, while the East is mainly the region from which industries transferred out.

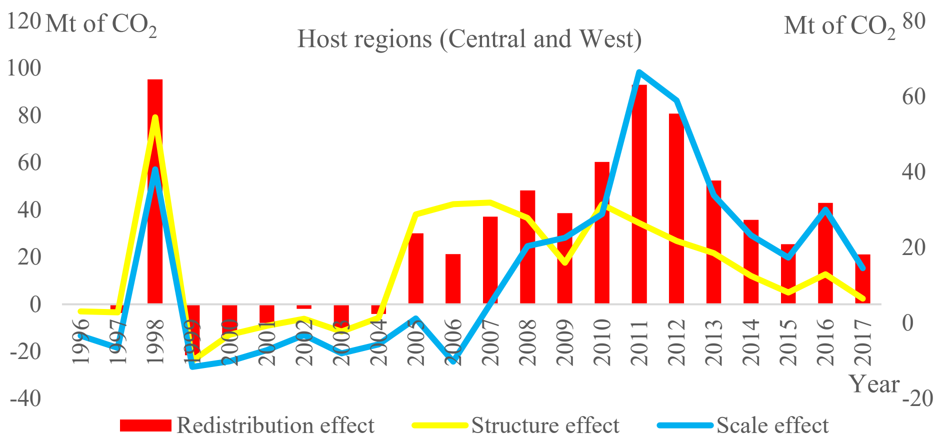
Though the Northeast was treated as a host region and received relevant policy support, according to our constructed macro-indicators, it remains a region experiencing industries transferring out due to slow economic growth (as shown in Figure S2 in the Supplementary Materials). We treat the Central and the West as new host regions, and the East and Northeast as regions where relevant activities are transferring out (home regions), and then calculate the respective effects of industry redistribution on carbon emissions for the home regions in question compared to the new host regions, as well as for the country as a whole. The results are presented in Figure 2.

Overall, the effects of taking in industries and other economic activities in the Central and the West regions cumulatively reach an increase of 619.74 Mt of CO_2 over the period 1995-2017, which is higher than the emission reduction effects in the East and the Northeast (–564.55 Mt of CO_2). Therefore, the emission increase effect of the shift in carbon-intensive industries is dominant for the whole country. The industrial and economic activity redistribution combined effect leads to a cumulative increase of 55.19 Mt of CO_2 in CO_2 emissions, of which 70.70% was due to the structural change effect (some sectors changing more than others).

From the dynamic perspective, since 2004, when the strategy of “the rise of Central China” was proposed by the China State Council in the “Report on the Work of the Government”, the Central and the West regions began to show a stable emission increase effect of industrial and economic sectoral transfer; they demonstrate an inverted U-shape trend over time. The period of 2014–2017 accounts for only 21.35% of the increase in CO_2 emission during 2005–2017, indicating that low-emission technology change occurred in the Central and the West when these regions, beginning to host carbon-intensive industries, also introduced advanced, cleaner technology. As a result, a carbon reduction effect in these regions emerges during 2014–2017.

The East and the Northeast also begin to show stable carbon reduction effect since 2000 when the strategy of “development of the West region” was proposed by the China State Council and industries began to move to West. The reduction value increased with time, with a cumulative decrease of 511.67 Mt of CO_2 in CO_2 emissions during 2002 to 2017. This indicates that as the gradual agglomeration of low-carbon intensive industries combines with the improvement of technology in higher carbon-intensive industries, the carbon reduction effect begins to increase in the East.

It is worth noting that since the China State Council released the document "Guidelines for Central and West Regions Undertaking Transferred Industries" in 2010, the industrial and economic sectoral redistribution effect displayed emission increase effect from 2011 to 2013 and increased 86.28 Mt of CO_2 in CO_2 emissions during these three years. This is because this policy stimulated many carbon-intensive industries shifting from the East to Central and West regions, and this led to an increase in carbon emissions. The continued refinement of industrial redistribution policy appears to have had a stable emission reduction effect from 2014 to 2017, reducing a cumulative of 58.62 Mt of CO_2 in CO_2 emissions during this period. This was followed by the release of the document "Guidance Directory for Industry Transfer" in 2012, which mainly targets optimisation of industries in the provinces Liaoning (in Northeast), Hebei (in East), and Shanxi (in West), previously home to a large share of heavy industry. Under the industrial redistribution policy, these provinces on average annually reduce 23.5, 14.2, 12.7 Mt of CO_2 in CO_2 emissions, respectively, during the period 2014–2017.



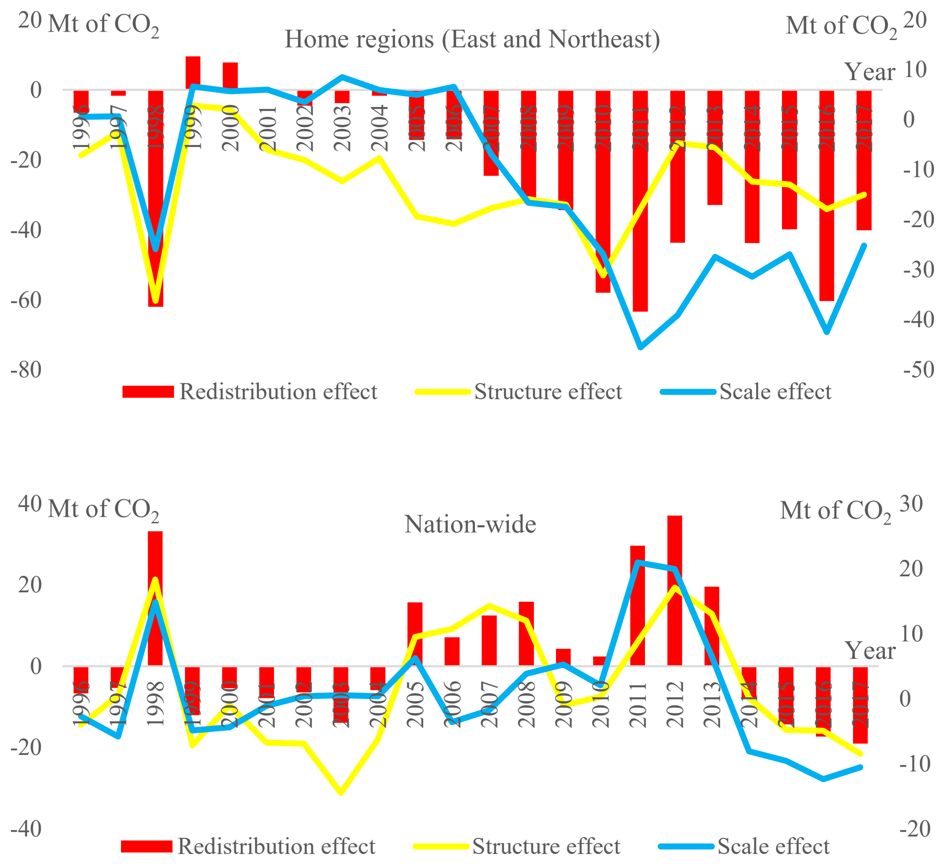


Figure 2. The overall CO_2 emission effect of industrial redistribution

Note: The results are from authors' calculations using the dataset.

4.2.2 Marginal effect of carbon emissions: how to optimise industrial distribution

From the analysis above, we can see that emission reductions emerged in the East and Northeast and began to be higher than emission increases in the Central and the West regions. Based on the LMDI method, we use Equation (9) to calculate the marginal effect of the redistribution changes in industrial and economic activities on CO_2 emissions. A higher marginal effect means higher climate change "cost" of this economic activity in a region. To reduce carbon emissions, this activity should transfer to regions with lower marginal effect of this activity or improve its production technology. The results are shown in Table 5 and Figure S3 in the Supplementary Materials.

The West shows a relatively high marginal effect of CO_2 emissions for industry, business and transportation sectors, indicating that it requires further technology upgrading to reduce climate change costs due to industry and economic redistribution. The East displays a relatively high marginal effect of changes in agriculture and construction activity, suggesting that it can further transfer agriculture out of its region, and improve technology to control emissions in the construction sector. The Northeast shows a relatively low marginal effect of CO_2 emissions for all sectors, and it can make efforts to develop high quality transportation and construction activities to attract investment and business. Similarly, the Central region also demonstrates a relatively low marginal carbon emissions effect.

Table 5: The average annual marginal effect of industrial redistribution on CO_2 emissions by region and type of activity (Mt of CO_2 per year), 1995–2017

Region	Industry	Agriculture	Business	Transportation	Construction
East	44.53	2.87	5.28	4.59	1.12
Central	59.76	2.72	4.76	4.64	0.89
West	113.13	2.83	8.45	7.62	1.04
Northeast	58.19	1.90	6.48	5.25	0.74

Note: The results are from authors' calculations using the dataset.

5. Discussion and further analysis: population migration and CO_2 emissions

The redistribution of industries also leads to population migration among regions, which affects CO_2 emissions as well (Hao et al., 2020; Hao et al., 2021). We investigate whether population migration in the period of study leads to an increase or decrease in CO_2 emissions for the country and for each region respectively. The results are presented in Table S4, S5, S6 and Figure S4, S5 in the Supplementary Materials.

We find that the population as a whole moves to the East, and population migration leads to an increase in CO_2 emissions. This is consistent with Rafiq et al. (2017) which finds that migration in China from one region to another during 2000-2013 results in an increase in CO_2 emissions. However, our results show that urban and rural population migration begin to show a stable emission reduction effect between 2012 and 2015, respectively.

We calculated the marginal effect of household CO_2 emissions for the urban and rural of the four regions. The East stays in the middle in terms of the marginal effect of household CO_2 emissions for urban population. The marginal effect of household CO_2 emissions of the urban population in the Northeast ranked highest across regions, and this is because of its high heating consumption in its relatively harsher winters. Under this condition, it is quite necessary to adjust the energy structure for heating in the Northeast. The marginal effect in the Central and the West regions stays relatively low. In order to refine policy to guide population distribution to favour climate action, policies that induce population migration to the Central and the West are needed. But it is necessary to bear in mind that with the living standards improving in these regions, population growth is likely to lead to an initial increase in CO_2 emissions before any decline per capita might occur.

6. Conclusions

This paper employs logarithmic mean Divisia index (LMDI) to analyse the dynamic net effects of industrial and economic activity redistribution on CO_2 emissions, in China over the period 1995–2017. To do this we use data from agriculture, industry, construction, business and transportation sectors in 30 provinces in China. We compare the emission increase effect of the transfer of carbon-intensive industries from "home" regions to new "host" regions and compare emission increases by region to counterbalancing emission reduction effects induced by shifts in location of low carbon-intensive industries and cleaner technologies.

Our results show that the redistribution of industry, business and construction sectors across regions increased CO_2 emissions, while that of the agriculture and transportation sectors reduced CO_2 emissions. Over our study period (1995-2017), the transfer in location of industry led to an increase in carbon emissions for the whole country. However, both the redistribution of other sectors and changes in the household sector – due to shifts in population -- began to have a stable emission reduction effect (since around 2014). This stabilisation trend followed the release of the document "Guidance Directory for Industry Transfer (2012)," which provides guidance for provinces taking in and/or developing industries based on their industrial foundation, resource endowment and environmental capacity. This research is thus indicating how the strategy of industry transfer in China is working in the long-run to reduce carbon emissions.

This study has important policy implications for China. Our results suggest that policies targeting the East region should aim to further transfer the agriculture sector to the Central and West regions (given the marginal emission effect of agriculture is much lower in the Central and West), and to upgrade technology in the construction sector. The government should also implement policies to support the Central region to host industries that are transferring in, including to attract population shifts needed to provide labour for these industries. The West shows low marginal changes in carbon emissions due to household sector, but high marginal changes in carbon emissions associated with increased industry, business, and transportation activities; therefore, the government should promote technology upgrading in this region and provide preferential policies to attract more inhabitants. The Northeast underperforms as a potential host region for the transfer of industries. Therefore, the Northeast needs to develop high-quality infrastructure, such as high-speed railways and roads, to attract investment and business, and it is also necessary to adjust the energy structure to accommodate industry transfer to the Northeast.

This study also has important policy implications for other developing countries with similar industrial redistribution policies to those in China. From our results, we can see that industrial redistribution is usually a long-term strategy for regional development within a county. With conducive and regionally-tailored policies, industrial redistribution within a county is not only an economic policy, but can also be also an important policy instrument to mitigate CO_2 emissions.

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Data availability statement

The data that support the findings of this study is available from the authors upon request.

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