The challenge of global carbon emissions will be unbearable if India undertakes industrial relocation from China

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Abstract

With the rise of labor costs in China, constraints on resources and environment, and ongoing geopolitical conflicts, India has emerged as the most likely candidate to undertake China's industrial relocation. This shift could undermine global efforts to cut carbon emissions. However, ex ante measurement of the environmental effects of such industrial relocation is poorly understood. Here we show that shifting the iPhone production from China to India doubles the production's carbon footprint. Overall, India's undertaking of China's industrial relocation will lead to increased carbon emissions and reduced global economic growth. The carbon burden surpasses the emission reductions achieved by the EU since the Copenhagen Climate Conference. At the sector level, the computer, basic metals, electronic equipment, and automotive sectors are the largest sources of incremental carbon emissions, ensuring these sectors are not substituted by India and promoting technological progress in developing countries are essential to offset the extra emissions.

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Introduction

The worsening global climate crisis, marked by rising temperatures, frequent extreme weather events, and rising sea levels, poses significant challenges to human society and ecosystems. Trade, a crucial component of global economic activity, plays a significant role in driving global carbon emissions and environmental changes [1-10]. Since the 2008 global financial crisis, the international political and economic environment has become increasingly volatile, with geopolitical conflicts and trade protectionism accelerating the restructuring of global value chains [11,12]. Recently, multinational corporations such as Apple, Siemens, and Samsung have been shifting their production tasks from China to Southeast Asia and South Asia, signaling a significant adjustment in the global industrial layout. China, known as the “world’s factory” due to its labor endowment and low-cost advantages, is seeing a shift as the era of cheap labor comes to an end [13-15]. Labor-intensive industries (such as the textile industry) and production links (such as assembly and processing) are diverting to other emerging economies [16,17]. India, with its vast market, low-cost labor, and strategic industrial policies like "Make in India" and "Production-Linked Incentive", has attracted a significant amount of industry relocation and become a prominent candidate to absorb the industrial relocation from China. While industrial relocation can drive economic development in the host country, the mass-scale transfer of industries from China to India could significantly reshape global greenhouse gas emissions and profoundly impact climate change mitigation efforts in the long-run. Therefore, in this paper, we aim to address this urgent question by quantifying the impacts of mass-scale industrial relocation from China to India on carbon mitigation.

Despite wide attention, explicit analysis of the challenge of balancing industrial relocation with climate change mitigation is far from complete. There are three main strands of literature relevant to our study. The first strand involves the measurement of industrial relocation [18-22], which is fundamental to empirical research on this topic. However, the existing measurement indicators are inadequate for effectively gauging the scale of an economy's industrial relocation. The second strand analyzes the drivers and mechanisms of industrial transfer and estimates its economic impact [23-35]. This body of literature mainly focuses on the effects on the home country, with relatively little research dedicated to the host country. Additionally, it largely overlooks environmental issues. The third strand addresses the environmental side effects of industrial relocation [36-42]. While this literature has substantially accounted for the ex post environmental impact of industrial relocation, few studies have quantified the ex ante environmental impact of industrial relocation, particularly the potential increase in global carbon emissions and its significant impact on the global climate and environment [43,44]. Moreover, most research focuses on industrial relocation from developed to developing countries, with little attention paid to industrial relocation among developing countries.

Considering that ex ante measurements of the environmental effects of industrial relocation have not been well conducted, we construct a carbon emission accounting model for India undertaking industrial relocation from China (as shown in Fig. 1). Firstly, using the theory of industrial relocation [45-48], we create a theoretical model for ex ante industry identification and scale measurement of industry relocation. Based on whether it is limited by undertaking capacity, we design two categories of scenarios for analysis: the ultra-long term (ULT) scenario and medium and long term (MLT) scenario. To further explore the possible outcomes of India's undertaking of China's industrial relocation, we subdivide the MLT scenario into three sub-scenarios: the benchmark (BM) scenario, the upper-limit (UL) scenario, and the lower-limit (LL) scenario. Finally, using the Inter-Country Input-Output (ICIO) model and the counterfactual analysis, we measure the environmental and economic effects of India's undertaking of China's industrial relocation.

We first measured the carbon impact of moving an iPhone production from China to India. We found that transferring the production of a 64GB of iPhone X to India leads to 68kg of carbon leakage, resulting in a 107.5% increase in the manufacturing carbon footprint, more than doubling the carbon emission. Building on this initial case study, we then expanded our analysis to changes in carbon emissions at both the overall and sectoral levels. The results show that India's undertaking of China's industrial relocation will significantly increase the global carbon burden. In the ultra-long term, global carbon emissions will rise by 855.5Mt CO_2, exceeding the carbon emission reduction achieved by every G7 country after the Copenhagen Climate Conference (2009-2021), and surpassing the carbon emission reductions by the EU (472.0 Mt CO_2) and part of the G20 (all G20 economies except China and India) (691.1Mt CO_2) in the same 12 years, reaching 77.8% of the emission reduction of all OECD countries in the same 12 years. In the medium and long term, under the benchmark scenario, the increase in global carbon emissions (396.5 Mt CO_2) from India's undertaking of China's industrial relocation is 39.4% of the emissions cut by all G7 countries, 84.0% by the EU and 36.1% by the OECD over the same 12 years. Decomposed by source, the increase in global carbon emissions mainly comes from the trade of intermediate products. From a sectoral perspective, the computer, basic metals, electrical equipment, and automotive sectors are the main contributors to the increase in carbon emissions. In the ultra-long term, these sectors account for 79.8% of the total increase in carbon emissions, while in the medium and long-term scenario, basic metals and automotives account for 80.5%. As a result, ensuring these sectors (computer, basic metals, and electrical equipment, automotive) are not substituted by India is crucial to offsetting the extra emissions caused by India's undertaking of China's industrial relocation. In addition, technological advancements in reducing pollutant intensity are urgently required in developing countries.

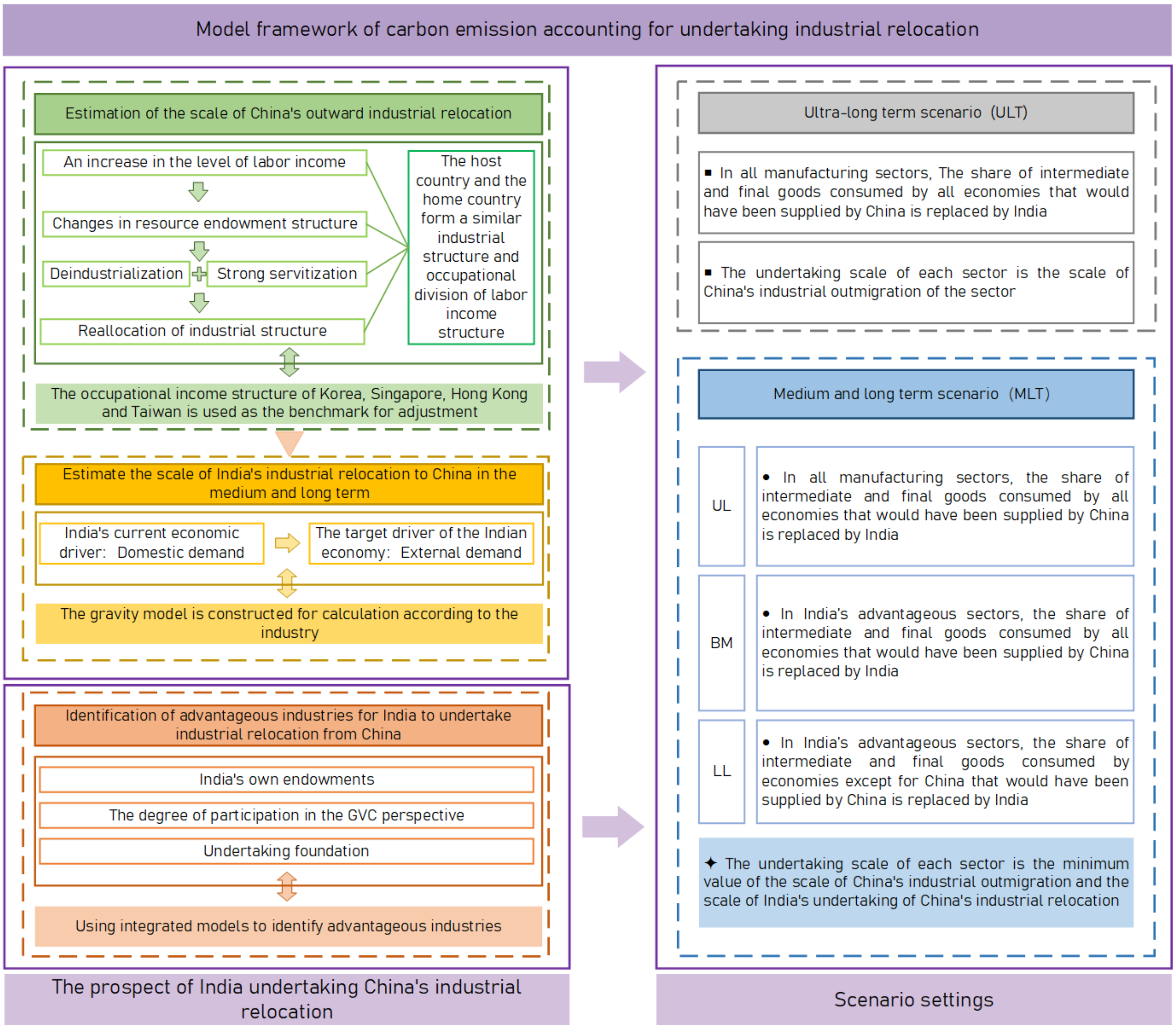

Fig. 1 Model framework of carbon emission accounting for undertaking industrial relocation

Methods

Measurement of carbon footprint change of the iPhone production transferred to India

Originally developed by Leontief [50], environmental input-output analyses have been widely used to illustrate the economy-wide environmental repercussions triggered by economic activities. Without loss of generality, let us consider a world economy with G economies and N sectors. Its economic structure is represented by the environmentally extended Inter-Country Input-Output (ICIO) model in Supplementary Table 3.

Denote matrix $\boldsymbol{Z}$ ($ng \times ng$ dimension) and matrix $\boldsymbol{Y}$ ($ng \times ng$ dimension) as the flows of intermediate goods products and final products among different economies, respectively:

$$\boldsymbol{Z} = \begin{pmatrix} \boldsymbol{Z}^{11} & \boldsymbol{Z}^{12} & \cdots & \boldsymbol{Z}^{1g} \\ \boldsymbol{Z}^{21} & \boldsymbol{Z}^{22} & \cdots & \boldsymbol{Z}^{2g} \\ \cdots & \cdots & \ddots & \cdots \\ \boldsymbol{Z}^{g1} & \boldsymbol{Z}^{g2} & \cdots & \boldsymbol{Z}^{gg} \end{pmatrix}, \quad \boldsymbol{Y} = \begin{pmatrix} \boldsymbol{Y}^{11} & \boldsymbol{Y}^{12} & \cdots & \boldsymbol{Y}^{1g} \\ \boldsymbol{Y}^{21} & \boldsymbol{Y}^{22} & \cdots & \boldsymbol{Y}^{2g} \\ \cdots & \cdots & \ddots & \cdots \\ \boldsymbol{Y}^{g1} & \boldsymbol{Y}^{g2} & \cdots & \boldsymbol{Y}^{gg} \end{pmatrix}$$

Where, its typical element z_{ij}^{sr} provides the intermediate input from sector $i\ (i = 1,2, \dots n)$ in economy $s(s = 1,2, \dots, g)$used by sector $j(j = 1,2, \dots n)$in economy $r(r = 1,2, \dots, g)$. In this ICIO model, the input coefficient matrix can be defined as $\boldsymbol{A} = \boldsymbol{Z}\widehat{\boldsymbol{X}}^{-1}$, where $\widehat{\boldsymbol{X}}$ denotes a diagonal matrix with the output vector $\boldsymbol{X}$ in its diagonal. $\boldsymbol{A}^{rr}$and $\boldsymbol{Y}^{rr}$ provide intra- economy flows of intermediate products and final products. $\boldsymbol{A}^{sr}$ and $\boldsymbol{Y}^{rr}$ (s ≠ r) represent trade in intermediate products and trade in final products, respectively.

So, the accounting balance of monetary flows between industrial sectors and regions is:

$$\begin{pmatrix} \boldsymbol{X}^{1} \\ \boldsymbol{X}^{2} \\ \vdots \\ \boldsymbol{X}^{g} \end{pmatrix} = \begin{pmatrix} \boldsymbol{Z}^{11} & \boldsymbol{Z}^{12} & \cdots & \boldsymbol{Z}^{1g} \\ \boldsymbol{Z}^{21} & \boldsymbol{Z}^{22} & \cdots & \boldsymbol{Z}^{2g} \\ \cdots & \cdots & \ddots & \cdots \\ \boldsymbol{Z}^{g1} & \boldsymbol{Z}^{g2} & \cdots & \boldsymbol{Z}^{gg} \end{pmatrix} + \begin{pmatrix} \sum_s \boldsymbol{Y}^{1s} \\ \sum_s \boldsymbol{Y}^{2s} \\ \vdots \\ \sum_s \boldsymbol{Y}^{gs} \end{pmatrix} \quad (1)$$

For each region, the monetary balance is:

$$\boldsymbol{X}^{r} = \boldsymbol{Z}^{r} + \boldsymbol{Y}^{r} + \textstyle\sum_s \boldsymbol{e}^{rs} - \sum_s \boldsymbol{e}^{sr} \quad (2)$$

where $\boldsymbol{e}^{rs}$ $(r \neq s)$ represents the exports from region r to s, and $\boldsymbol{Y}^{r} = \sum_s \boldsymbol{Y}^{rs}$. Here we need to focus on embodied emissions in the bilateral trade of both intermediate and final consumption by tracing the domestic supply chain. Specifically, we focus only on the domestic production component and exclude imports of intermediate products ($\boldsymbol{Z}^{r}$) and final products ($\boldsymbol{Y}^{r}$), The row equilibrium can be expressed as Eq. (3).

$$\boldsymbol{X}^{r} = \boldsymbol{Z}^{rr} + \boldsymbol{Y}^{rr} + \textstyle\sum_s \boldsymbol{e}^{rs} \quad (3)$$

$$\boldsymbol{T}^{rs} = \boldsymbol{FT}^{r}(\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1}\boldsymbol{e}^{rs} = \boldsymbol{h}^{r}\boldsymbol{e}^{rs} \quad (4)$$

where $\boldsymbol{FT}^{r}$ is the direct emission intensity in region r, which is obtained by dividing the CO_2 emissions in each sector by the corresponding output. $\boldsymbol{h}^{r} = \boldsymbol{FT}^{r}(\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1}$ is the embodied emission intensity, which captures direct and indirect carbon emissions along the supply chain to produce a unit of product or service. So, its typical element t_i^{rs} provides the emissions displaced from region r to s due to exports from sector i in region r to region s.

The carbon leakage caused by shifting the iPhone production from China to India is:

$$\sum_s \boldsymbol{F}^* t_{com}^{India} (\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1} \boldsymbol{e}^{rs} - \boldsymbol{F}^* t_{com}^{China} (\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1} \boldsymbol{e}^{rs} \quad (5)$$

where $\boldsymbol{F}^*\boldsymbol{T}^r$ is the direct emission intensity in region r, which is obtained by dividing the CO_2 emissions（get rid of electricity）in each sector by the corresponding output.

Identifying the advantageous industries for India in undertaking industrial relocation from China

The endowment of an economy serves as the starting point for analyzing economic development. Different endowment structures lead to varying production capabilities across industries in different economies, resulting in distinct advantage sectors. International industrial relocation typically accompanies the flow of transnational capital and the integration of domestic and foreign market resources and products. Therefore, host countries with higher participation in the global value chain are more conducive to the transfer of production activities to them. The absorption of industrial relocation from other economies depends not only on the host economy's production endowment but also requires certain infrastructure, industrial support, and a favorable business environment. Past records of industrial absorption can serve as a comprehensive consideration of these indicators. To this end, we draw upon the quantitative evaluation framework proposed by Zhang et al. [51] to assess the prospects of an economy's absorption of international industrial relocation. This framework integrates the Locational Quotient Index, the Global Value Chain Participation Measurement Model proposed by Wang et al. [45,46], and the Industrial Relocation Value Calculation Method proposed by Gao et al. [47] to identify the advantageous industries for India in absorbing industrial relocation from China (see in supplementary note 1).

This study utilizes ICIO tables released by the Organisation for Economic Co-operation and Development (OECD), covering all OECD economies and some non-member economies (including all G20 economies) from 1995 to 2020. The ICIO tables contain industry-to-industry flow matrices of domestic production and imports of goods and services, calculated in current-price million USD, with each economy comprising 45 industries. This study focuses specifically on manufacturing sectors. To mitigate the impact of individual annual data on overall trends, the study divides the time period into four segments: 1996-2002, 2002-2008, 2008-2014, and 2014-2020. This time segmentation aids in a more comprehensive understanding of India's role in the global value chain across different periods. During 2002-2008, global trade experienced rapid expansion, but the 2008 financial crisis led to a significant decline in global trade and investment, and India's economic growth also slowed. Since 2014, India has implemented a series of policy measures, including strengthening trade protection and export subsidies, to promote the development of the manufacturing industry. Thus, we have identified the advantageous industries for India in absorbing industrial relocation from China (as shown in Table 1).

Estimation of the scale of China's outward industrial relocation

As labor income levels rise, the resource endowment structure of each economy undergoes changes. A phenomenon observed in the manufacturing exports of an economy is the simultaneous occurrence of "deindustrialization" and "services strengthening." This means that as per capita GDP increases, the proportion of productive occupational income in total exports gradually declines [46]. Correspondingly, its industrial structure will be reconfigured. The differences in occupational income structure among economies at different income levels also reflect the differences in labor endowment between economies and the structural changes in manufacturing production. In other words, the host country will gradually form an industrial division of labor similar to that of the home country, corresponding to a similar occupational income structure.

In this study, the Occupational Database (OD) is first mapped to the OECD's 45 sectors according to the 2-digit International Standard Classification of Occupations (ISCO). For economies that cannot be directly mapped, two principles are used to determine the mapping: (1) use economies with similar regional income levels for correspondence; (2) for economies without reference, use the average proportion of economies with similar per capita income levels, weighted by each economy's value added. Per capita income levels are primarily divided using per capita GDP data from the World Bank database. Then, based on the occupational nature of labor factors and using the occupational income structure of the Asian Tigers (South Korea, Singapore, Hong Kong, Taiwan) as a reference, the occupational income structure of China is adjusted to obtain the proportion of each industry that needs to be transferred. This yields the proportion of China's outward industrial transfer for each industry.

Estimate the scale of India's industrial relocation to China in the medium and long term

In recent years, India's overall growth has been "too much" driven by domestic demand, resulting in a growth rate of imports that is much higher than that of exports, which has hindered the development of the Indian economy. Indian Prime Minister Narendra Modi, upon taking office, pledged to revitalize his flagship policy of "Make in India," aiming to develop the country into a global manufacturing and export powerhouse, thereby consolidating India's position as one of the world's fastest-growing major economies. In its latest foreign trade policy announced in 2023, India has begun establishing export processing zones at the county level. Therefore, India has taken measures to unleash its untapped export potential, focusing on developing an export-oriented economy and integrating into the international market. This study categorizes the samples into two groups based on whether the export orientation of the industry in the economy is greater than that of India. We can use Eq. (6) to estimate India's export potential by industry.

$$ln\,EX_{ij} = \alpha_0 + \alpha_1\,ln\,Va_i + \alpha_2\,ln\,Va_j + \alpha_3\,ln\,DIS_{ij} + \alpha_4\,ln\,LAN_{ij} + \mu_{ij} \quad (6)$$

Here, EX_{ij} is the export value from economy i to economy j; Va_i and Va_j represent the value-added of economy i and economy j respectively; DIS_{ij} represents the geographical distance between the capitals of economy i and economy j; LAN_{ij} indicates whether economy i and economy j share a common language; and μ_{ij} is the disturbance term.

Thus, the expression min{ the proportion of China's industry outward transfer, India's export potential for the industry / China's export scale of this industry } can be understood as the proportion of industries in India's undertaking of China's industrial relocation. The results are presented in Supplementary Table 5.

Scenario settings

In this work, two categories of scenarios are designed to conduct the analysis based on the length of time, that is, the Ultra-long term (ULT) scenario and Medium and long-term (MLT) scenario. In the ultra-long term scenario, an economy's productive capacity breaks through existing capacity constraints. In this scenario, the scale of industrial relocation undertaken by India will not be limited by its own capacity and will mainly depend on the transfer from the home country. In the medium and long-term scenario, an economy's capacity to undertake the relocation will be limited. To further explore the possible outcomes of India's undertaking of China's industrial relocation, we designed three sub-scenarios under the medium and long-term scenario: the benchmark (BM) scenario, upper-limit (UL) scenario, and lower-limit (LL) scenario.

BM scenario:

In this scenario, we make the following assumption: for the sectors where India has an advantage in undertaking China's industrial relocation (as shown in Table 1), the share of intermediate and final goods originally provided by China in the global economy will be replaced by India. The ratio of transfers is the MLT ratio in Table 1. We fully consider the previous cost advantages of the two economies when identifying the advantageous sectors. Thus, the BM scenario is used as the reference case, as it is the most consistent with the classical theory of comparative advantage in economics.

UL scenario:

In this scenario, we make the following assumption: for all the sectors where India has an advantage in undertaking China's industrial relocation (as shown in Table 1), the share of intermediate and final goods originally provided by China in the global economy will be replaced by India. The ratio of transfers is the MLT ratio also shown in Table 1. Over time, more sectors in the host country will undertake the industrial relocation from the home country. From the perspective of the home country, rising labor costs lead to the relocation of its sectors. The sectors with the most comparative advantages in the host country will be the first to shift outward. As time progresses, the home country's economy continues to develop, resulting in more sectors being transferred outside. From the perspective of the host country, its own economy also develops over time, leading to more industries showing comparative advantages. Therefore, the UL scenario can be used as an upper limit for the MLT scenarios.

LL scenario:

In this scenario, we make the following assumption: for the sectors where India has an advantage in undertaking China's industrial relocation (as shown in Table 1), the share of intermediate and final goods originally provided by China in the global economy, except for China, will be replaced by India. The ratio of transfers is the MLT ratio also shown in Table 1. We set up this scenario based on several factors: on the one hand, the lack of global economic recovery may drag down India's pace of attracting foreign capital; on the other hand, the "industrial reshoring" policies adopted by the United States through high subsidies may also inhibit India’s industrial relocation efforts. From China's perspective, the significant role of the manufacturing industry in economic growth and employment may prompt China to try to slow down the speed of industrial outmigration. In addition, from India’s perspective, manufacturing automation, which threatens 69% of India's employment [52], may impact India's capacity to undertake industrial relocation. Therefore, the LL scenario can be used as a lower limit for the MLT scenarios.

Characterizing the Evolution of Industrial Layout

India's absorption of China's outward industrial relocation will lead to shifts in the global industrial layout. From a production perspective, manufacturing firms will choose which regions to import their necessary intermediate goods from. From a consumption perspective, consumers will decide which regions to import from to meet their final demand. The former results in changes to the structure of intermediate goods sources, while the latter results in changes to the structure of final goods sources.

For changes in the structure of final goods sources, we refer to the logic of the Hypothetical Extraction Method (HEM) [53], transferring the final demand from other economies for Mainland China to final demand for India. Denote the following as the flows of final products among different economies:

$$\boldsymbol{Y} = \begin{pmatrix} \boldsymbol{Y}^{11} & \cdots & \boldsymbol{Y}^{1c} & \cdots & \boldsymbol{Y}^{1i} & \cdots & \boldsymbol{Y}^{1g} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{Y}^{c1} & \cdots & \boldsymbol{Y}^{cc} & \cdots & \boldsymbol{Y}^{ci} & \cdots & \boldsymbol{Y}^{cg} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{Y}^{i1} & \cdots & \boldsymbol{Y}^{ic} & \cdots & \boldsymbol{Y}^{ii} & \cdots & \boldsymbol{Y}^{ig} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{Y}^{g1} & \cdots & \boldsymbol{Y}^{gc} & \cdots & \boldsymbol{Y}^{gi} & \cdots & \boldsymbol{Y}^{gg} \end{pmatrix}$$

Scenario BM/UL: In this scenarios, the share of final goods in the manufacturing sector supplied by China is replaced by India, represented by the replacement proportion matrix $\boldsymbol{q}$. Here, $\boldsymbol{q} = (q^1, q^2, \dots, q^n)$, where $q^k = 0$ if industry k does not undergo transfer. Under this scenario, the flows of final products among different economies are defined as follows:

$$
\boldsymbol{Y}_{BM/UL}{}^{*}=\begin{pmatrix}
\boldsymbol{Y}^{11} & \cdots & \boldsymbol{Y}^{1c} & \cdots & \boldsymbol{Y}^{1i} & \cdots & \boldsymbol{Y}^{1g}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
(\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{c1} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{cc} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{ci} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{cg}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
\boldsymbol{Y}^{i1}+\boldsymbol{q}_f\boldsymbol{Y}^{c1} & \cdots & \boldsymbol{Y}^{ic}+\boldsymbol{q}_f\boldsymbol{Y}^{cc} & \cdots & \boldsymbol{Y}^{ii}+\boldsymbol{q}_f\boldsymbol{Y}^{ci} & \cdots & \boldsymbol{Y}^{ig}+\boldsymbol{q}_f\boldsymbol{Y}^{cg}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
\boldsymbol{Y}^{g1} & \cdots & \boldsymbol{Y}^{gc} & \cdots & \boldsymbol{Y}^{gi} & \cdots & \boldsymbol{Y}^{gg}
\end{pmatrix} \tag{7}
$$

Scenario LL: In this scenario, the share of final goods in the manufacturing sector supplied by China, excluding China's own consumption, is replaced by India. The replacement proportion matrix is $\boldsymbol{q}$. Under this scenario, the flows of final products among different economies are defined as follows:

$$
\boldsymbol{Y}_{LL}{}^{*}=\begin{pmatrix}
\boldsymbol{Y}^{11} & \cdots & \boldsymbol{Y}^{1c} & \cdots & \boldsymbol{Y}^{1i} & \cdots & \boldsymbol{Y}^{1g}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
(\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{c1} & \cdots & \boldsymbol{Y}^{cc} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{ci} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_f)\boldsymbol{Y}^{cg}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
\boldsymbol{Y}^{i1}+\boldsymbol{q}_f\boldsymbol{Y}^{c1} & \cdots & \boldsymbol{Y}^{ic} & \cdots & \boldsymbol{Y}^{ii}+\boldsymbol{q}_f\boldsymbol{Y}^{ci} & \cdots & \boldsymbol{Y}^{ig}+\boldsymbol{q}_f\boldsymbol{Y}^{cg}\\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots\\
\boldsymbol{Y}^{g1} & \cdots & \boldsymbol{Y}^{gc} & \cdots & \boldsymbol{Y}^{gi} & \cdots & \boldsymbol{Y}^{gg}
\end{pmatrix} \tag{8}
$$

For intermediate goods, due to the differences in technical conditions across economies, the consumption of Chinese intermediate goods by other economies cannot be directly transferred to India, and thus, the method used for final goods cannot be applied here. This study adopts the approach from Xu & Dietzenbacher [54] and Su & Ang [55] to perform a structural decomposition analysis (SDA) multiplicative decomposition on the direct consumption coefficient matrix $\boldsymbol{A}$, decomposing it into a production technology matrix $\boldsymbol{P}$ and a sourcing structure matrix $\boldsymbol{U}$.

According to the meaning of the direct consumption coefficients, $\boldsymbol{P}^{*r}=\sum_{s=1}^{g}\boldsymbol{A}^{sr}$represents the intermediate consumption in region r from all other regions, regardless of the source (including itself). The notation $\boldsymbol{P}^{*'}=(\boldsymbol{P}^{*1}\quad \boldsymbol{P}^{*2}\quad \cdots\quad \boldsymbol{P}^{*g})$ indicates the intermediate consumption in all regions without distinguishing the source. By horizontally stacking $\boldsymbol{P}^{*'}$, we obtain the global intermediate input production technology stacking matrix $\boldsymbol{P}$, as shown in Eq. (9).

$$
\boldsymbol{P}=\begin{pmatrix}
\boldsymbol{P}^{*1} & \boldsymbol{P}^{*2} & \cdots & \boldsymbol{P}^{*g}\\
\boldsymbol{P}^{*1} & \boldsymbol{P}^{*2} & \cdots & \boldsymbol{P}^{*g}\\
\vdots & \vdots & \ddots & \vdots\\
\boldsymbol{P}^{*1} & \boldsymbol{P}^{*2} & \cdots & \boldsymbol{P}^{*g}
\end{pmatrix} \tag{9}
$$

Let $\boldsymbol{U}^{sr}$ represent the element-wise division of $\boldsymbol{A}^{sr}$ by $\boldsymbol{P}^{*r}$. Thus, $\boldsymbol{U}^{sr}$ represents the proportion of intermediate goods imported by region r from region s relative to all intermediate goods imported by region r Consequently, we obtain the global intermediate input sourcing structure matrix $\boldsymbol{U}$ as shown in Eq. (10).

$$
\boldsymbol{U}=\begin{pmatrix}
\boldsymbol{U}^{11} & \boldsymbol{U}^{12} & \cdots & \boldsymbol{U}^{1g}\\
\boldsymbol{U}^{21} & \boldsymbol{U}^{22} & \cdots & \boldsymbol{U}^{2g}\\
\vdots & \vdots & \ddots & \vdots\\
\boldsymbol{U}^{g1} & \boldsymbol{U}^{g2} & \cdots & \boldsymbol{U}^{gg}
\end{pmatrix} \tag{10}
$$

Under the BM, UL and LL scenarios, the source structure matrix of global intermediate inputs is:

$$\boldsymbol{U}_{BM/UL}{}^{*}=\begin{pmatrix} \boldsymbol{U}^{11} & \cdots & \boldsymbol{U}^{1c} & \cdots & \boldsymbol{U}^{1i} & \cdots & \boldsymbol{U}^{1g} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{c1} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{cc} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{ci} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{cg} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{U}^{i1}+\boldsymbol{q}_i\boldsymbol{U}^{c1} & \cdots & \boldsymbol{U}^{ic}+\boldsymbol{q}_i\boldsymbol{U}^{cc} & \cdots & \boldsymbol{U}^{ii}+\boldsymbol{q}_i\boldsymbol{U}^{ci} & \cdots & \boldsymbol{U}^{ig}+\boldsymbol{q}_i\boldsymbol{U}^{cg} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{U}^{g1} & \cdots & \boldsymbol{U}^{gc} & \cdots & \boldsymbol{U}^{gi} & \cdots & \boldsymbol{U}^{gg} \end{pmatrix} \quad (11)$$

$$\text{and } \boldsymbol{U}_{LL}{}^{*}=\begin{pmatrix} \boldsymbol{U}^{11} & \cdots & \boldsymbol{U}^{1c} & \cdots & \boldsymbol{U}^{1i} & \cdots & \boldsymbol{U}^{1g} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{c1} & \cdots & \boldsymbol{U}^{cc} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{ci} & \cdots & (\boldsymbol{1}-\boldsymbol{q}_i)\boldsymbol{U}^{cg} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{U}^{i1}+\boldsymbol{q}_i\boldsymbol{U}^{c1} & \cdots & \boldsymbol{U}^{ic} & \cdots & \boldsymbol{U}^{ii}+\boldsymbol{q}_i\boldsymbol{U}^{ci} & \cdots & \boldsymbol{U}^{ig}+\boldsymbol{q}_i\boldsymbol{U}^{cg} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \boldsymbol{U}^{g1} & \cdots & \boldsymbol{U}^{gc} & \cdots & \boldsymbol{U}^{gi} & \cdots & \boldsymbol{U}^{gg} \end{pmatrix} \quad (12)$$

Accounting for the carbon-emission and value-added changes

India's undertaking industrial relocation from China lead to changes in multilateral trade flows resulting in value-added and trade-related carbon emissions changes. We adopt the environmentally extended ICIO model (see Supplementary Table 3) to account for these carbon-emission and value-added changes.

According to the row balance of the input-output table, the gross output vector $\boldsymbol{X}$ (ng dimension) can be expressed as Eq. (13).

$$\boldsymbol{X}=(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \quad (13)$$

Where $\boldsymbol{\mu}$ is a summation vector of appropriate length with all elements being ones, and $\boldsymbol{B}=(\boldsymbol{I}-\boldsymbol{A})^{-1}$ is the famous inverse Leontief matrix, which is also known as the complete demand coefficient matrix, reflecting the demand for the total output of each sector in order to obtain the unit final product.

Let $\boldsymbol{V}=\begin{pmatrix}\boldsymbol{V}^1\\ \boldsymbol{V}^2\\ \vdots\\ \boldsymbol{V}^g\end{pmatrix}$ and $\boldsymbol{CE}=\begin{pmatrix}\boldsymbol{CE}^1\\ \boldsymbol{CE}^2\\ \vdots\\ \boldsymbol{CE}^g\end{pmatrix}$, which are both ng-dimension vectors, be the CO_2 emission coefficient vector, and the ratio of value-added vector, respectively. The elements v_i^r in vector $\boldsymbol{V^S}$ represent the value-added per unit of output for industry i in region r, and the elements ce_i^r in vector $\boldsymbol{CE^S}$ represent the carbon emissions per unit of output for industry i in region r. Then, the CO_2 emission vector $\mathbf{CEa}$ and value-added vector $\mathbf{Va}$ can be written as Eq. (14) and Eq. (15).

$$\mathbf{Va}=\widehat{\boldsymbol{V}}(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \quad (14)$$

$$\mathbf{CEa}=\widehat{\boldsymbol{E}}(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \quad (15)$$

where $\widehat{\boldsymbol{V}}$ and $\widehat{\boldsymbol{E}}$ represent the diagonalized matrix for $\boldsymbol{V}$ and $\boldsymbol{E}$, respectively.

Here, we use counterfactual analysis and draw on the logic of HEM to obtain the change in value-added (DVA) and the change in carbon emissions (DEA) in each region of the world. This represents the difference in value-added and carbon emissions between the actual situation and the hypothetical situation, respectively.

$$DVA = \widehat{\boldsymbol{V}^*}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \widehat{\boldsymbol{V}}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{16}$$

$$DEA = \widehat{\boldsymbol{E}^*}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \widehat{\boldsymbol{E}}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{17}$$

The left side of Eq. (14) and Eq. (15) represents global value-added and global CO_2 emissions, respectively. This equation can be adapted to calculate the value-added (Va^s) and CO_2 emissions (CEa^s) in a specific economy s. This can be obtained by replacing the vector $\boldsymbol{V}$ in Eq. (14) with vector $\boldsymbol{V}^{\boldsymbol{S}*}$, and replacing the vector $\boldsymbol{CE}$ in Eq. (15) with vector $\boldsymbol{CE}^{\boldsymbol{S}*}$. Thus, the value-added and carbon emission in region s driven by final demand can be expressed as:

$$\mathrm{Va}^s = \boldsymbol{V}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{18}$$

$$\mathrm{CEa}^s = \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{19}$$

Where $\boldsymbol{V}^{\boldsymbol{S}*} = \begin{pmatrix} \boldsymbol{0} \\ \vdots \\ \boldsymbol{V}^{\boldsymbol{S}} \\ \vdots \\ \boldsymbol{0} \end{pmatrix}$, $\boldsymbol{CE}^{\boldsymbol{S}*} = \begin{pmatrix} \boldsymbol{0} \\ \vdots \\ \boldsymbol{CE}^{\boldsymbol{S}} \\ \vdots \\ \boldsymbol{0} \end{pmatrix}$, and the superscript $'$ denotes the transpose of the vector.

Following the same logic as above, we obtain the changes in value-added (DVA^s) and the changes in carbon emissions (DEA^s) for region s, expressed as:

$$DVA^s = \boldsymbol{V}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A}^*)^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \boldsymbol{V}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{20}$$

$$DEA^s = \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A}^*)^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{21}$$

Eq. (20) and Eq. (21) enables us to consider the changes in both trade in intermediate products and trade in final products.

Through structural decomposition analysis, we can obtain the source structure of carbon emission changes (DEA^s) through both the intermediate goods trade component (${DEA^s}_{ip}$) and the final goods trade component from China (${DEA^s}_{fp}$).

$${DEA^s}_{ip} = \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A}^*)^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} \tag{22}$$

$${DEA^s}_{fp} = \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}^*\boldsymbol{\mu} - \boldsymbol{CE}^{\boldsymbol{S}*'}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y}\boldsymbol{\mu} \tag{23}$$

Results

Carbon leakage from shifting iPhone production to India

We first analyze the value added and carbon footprint of the iPhone X production chain to estimate the carbon leakage caused by shifting production from China to India. The iPhone production chain is particularly insightful as it involves the prominent sector of computer, electronic and optical equipment. Xing [49] shows that China's production gains was $104 in value added, or 25.4% of the total production cost of $409.5 (Fig. 2a). According to the iPhone X environmental report released by Apple, the total carbon footprint of the iPhone X is 79 kg, with the production stage accounting for 63.2 kg (80%). We estimated that China's carbon intensity in the iPhone X production chain in 2018 was 0.36 kg/USD, leading to a carbon footprint of 37.18 kg, which is 59.5% of the total production carbon footprint (Fig. 2b). This indicates that China’s carbon emissions are disproportionately high compared to its value-added share. Fig. 2c shows that when the Chinese part of the iPhone production chain is transferred to India, the total production carbon emissions of the iPhone X will increase by 68.0 kg, which is a 107.5% increase, doubling the overall carbon footprint to 147.0 kg. Overall, shifting the production of the entire iPhone industry chain will increase carbon emissions by 14.8 million tons.[2] Thus, from the perspective of the iPhone alone, the result suggests that India’s undertaking of China’s industrial relocation will significantly increase carbon emissions.

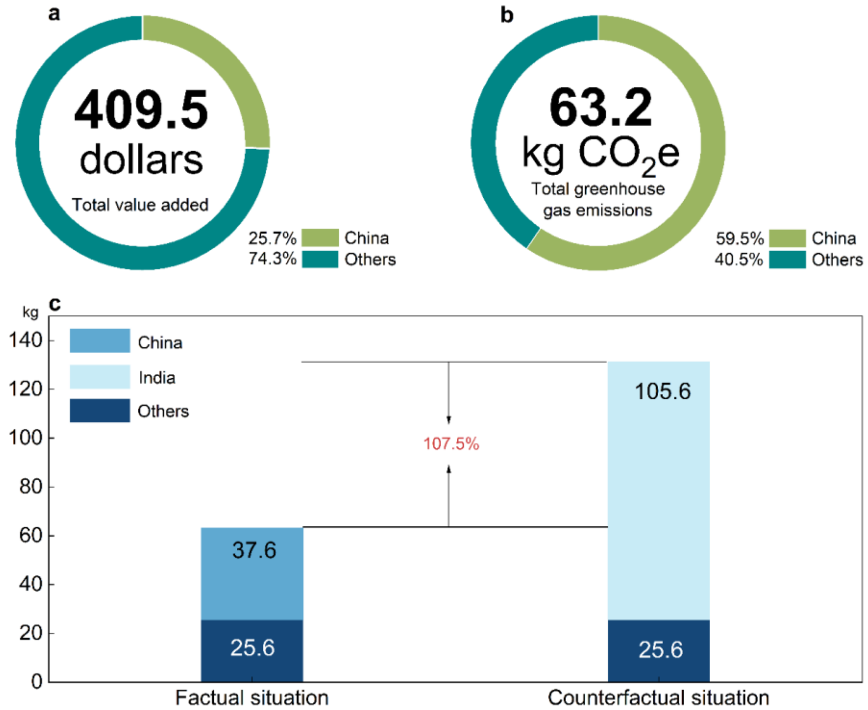

Fig. 2： CO_2 emission burdens in production from shifting an iPhoneX-64GB production to India. a shows that the value added of producing an iPhone X in China accounts for 25.7% of the total value added. b shows that the carbon emissions of producing an iPhone X in China account for 59.5% of the total carbon emissions. c illustrates the movement of the overall production carbon footprint.

[2] This calculation is based on 217.5 million units iPhone sales released by Apple Inc. Summary Data in 2017Q3-2018Q3. Among them, 2017Q4 is 46.7 million units,2018Q1 is 77.3 million units,2018 Q2 is 52.2 million units,2018 Q3 is 41.3 million units.

More CO2 emissions, and less economic growth

India's undertaking of China's industrial relocation will bring about changes in the global industrial layout. Due to differences in resource endowment and technological levels between the host and home country, these changes often result in variations in the global carbon emission levels. We design two categories of scenarios based on the length of time: the ultra-long term (ULT) scenario and the medium and long term (MLT) scenario. In the ULT scenario, the production capacity can break through the existing capacity limit, while it will be limited in the MLT scenario. Additionally, we subdivide the MLT scenario into three sub-scenarios: the benchmark (BM) scenario, the upper-limit (UL) scenario, and the lower-limit (LL) scenario. As shown in Fig. 3, in the ULT scenario, the sectors with the highest proportion of transfers are Paper products and printing, Wood and products of wood and cork, and Coke and refined petroleum products. In the MLT scenario, the top three sectors are Coke and refined petroleum products, Food products, beverages and tobacco, and Motor vehicles, trailers and semi-trailers.

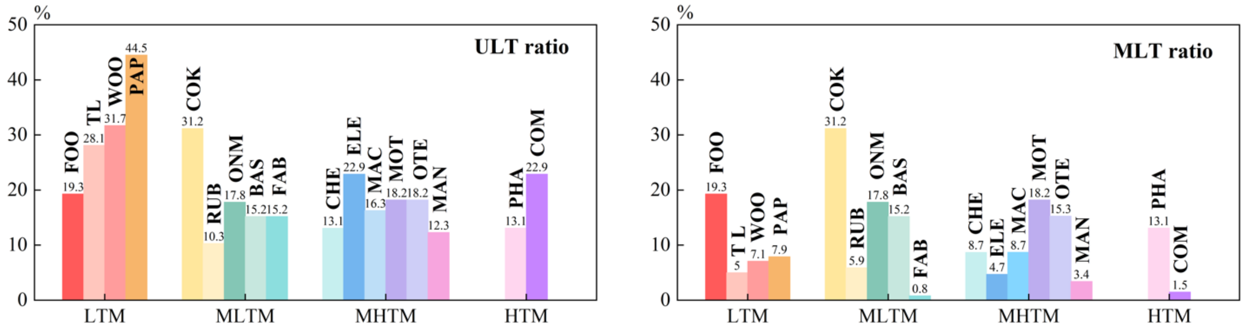

Fig. 3： Proportion of transfers for ULT and MLT scenarios. According to the OECD technology density classification, the manufacturing industry is divided into four categories, namely low-technology manufacturing (LTM), medium-low technology manufacturing (MLTM), medium-high technology manufacturing (MHTM) and high-tech manufacturing (HTM).

Table 1 shows eight advantageous sectors for India to undertake China's industrial relocation. According to the OECD's classification of manufacturing technology intensity, these sectors are mainly concentrated in low-tech and medium-low-tech sectors. Only two sectors, namely computer, electronic and optical equipment, and other transport equipment, belong to the medium-high technology sector.

Table 1： India's advantageous sectors for undertaking industrial relocation from China

Types of advantageous	Advantage sectors
Optimal advantage	Food products, beverages and tobacco
	Basic metals
Suboptimal advantage	Paper products and printing
	Other non-metallic mineral products
	Other transport equipment
Medium advantage	Computer, electronic and optical equipment
	Wood and products of wood and cork

The changes in global carbon emissions caused by India's undertaking of China's industrial relocation are shown in Fig. 4a. From a global perspective, this relocation will have a negative impact on the global environment. In the ULT scenario, this industrial relocation will increase global carbon emissions by 855.5Mt CO_2. In the MLT scenario, this industrial relocation will increase global carbon emissions by 23.8 to 399.6 Mt CO_2, with the benchmark (BM) scenario increasing emissions by 396.5Mt CO_2. The environmental impact of this industrial relocation affects not only the home country (China) and the host country (India), but also other regions. In the ultra-long run, this industrial relocation will add 52.2Mt CO_2 to the rest of the world, accounting for 6.1% of the global increase. In the BM scenario, it will add 13.9 Mt CO_2 to the rest of the world, accounting for 3.5% of the increase in global carbon emissions. In the UL scenario, this industrial relocation will add 52.2Mt CO_2 (6.1%), and in the LL scenario, it will add 0.8Mt CO_2 (3.4%).

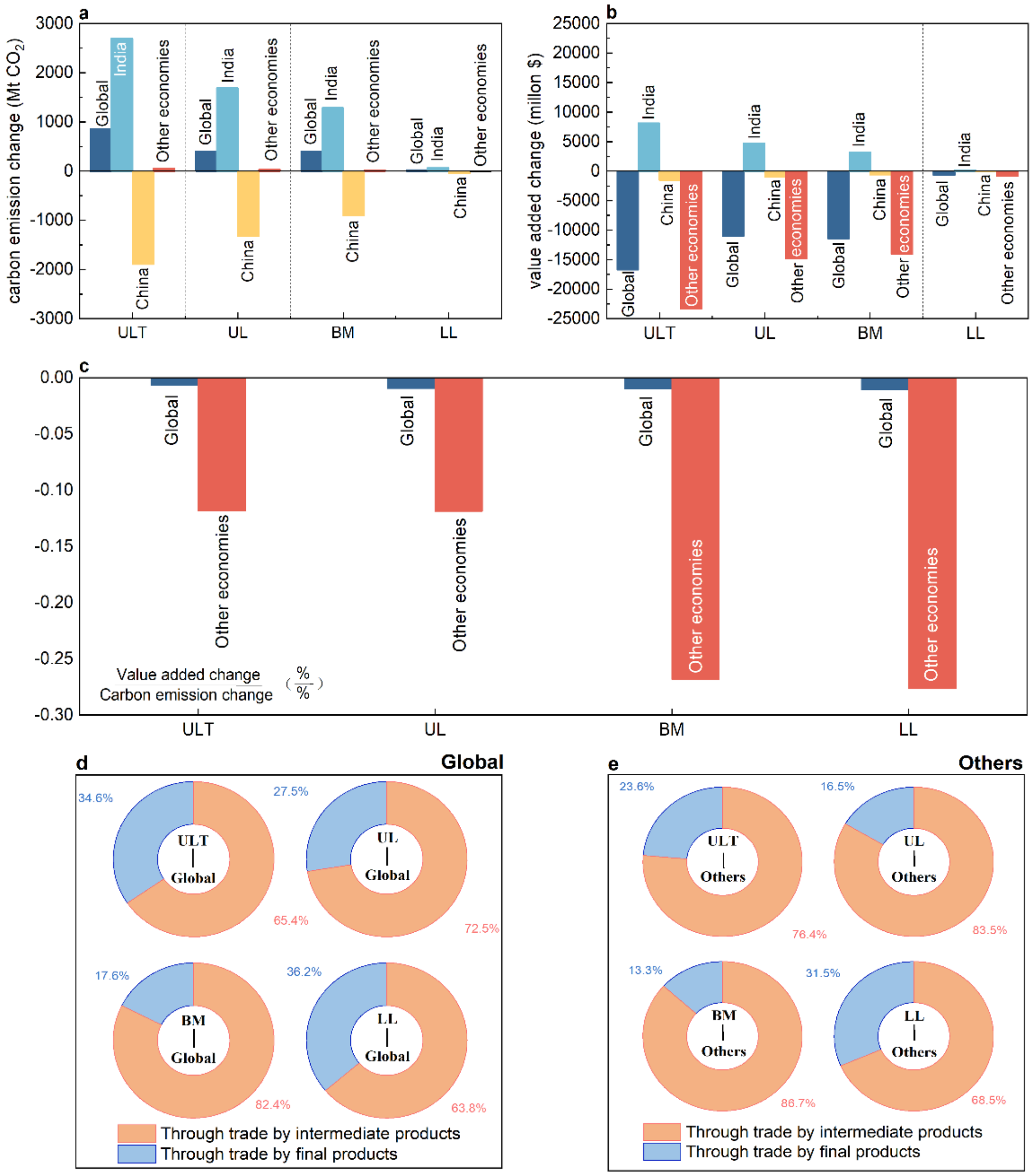

Fig. 4 The emission and economic effect of industrial relocation. a shows the environmental effect of India's undertaking of China's industrial relocation, b shows its corresponding economic effects, and c shows the comprehensive results of the economic and environmental effects. d,e gives the source of the amount of change in CO_2 emissions under the ULT, UL, BM, and LL scenarios.

In addition to accounting for the changes in carbon emissions caused by India's undertaking of China's industrial relocation, we also measure the associated economic effects (Fig. 4b). We find that this industrial relocation process not only increases global carbon emissions but also reduces the global GDP. In the ULT scenario, this industrial relocation will decrease global value added by 16,712.1 million USD. In the MLT scenarios (UL, BM and LL), global value added will decrease by 10,982.2, 11,412.9, and 706.2 million USD respectively. As shown in Figure 4b, excluding China and India, other regions will also experience economic downturns due to this relocation. In the ULT scenario, value added in other economies will decrease by 23,273.4.1 million USD, exceeding the negative impact on the global economy. In the MLT scenarios (UL, BM and LL), global value added will decrease by 14,807.0, 14,046.2, and 835.7 million USD, respectively, again exceeding the negative impact on the global economy.

Fig. 4c shows the comprehensive effect of India's undertaking of China's industrial relocation on the global economy and other economies excluding China and India. The change in value added divided by the change in carbon emissions is negative, indicating the double negative effect of this industrial relocation on both the economy and the environment. Additionally, this ratio is significantly higher for other regions compared to the global level, indicating that other regions bear a greater negative effect.

As shown in Fig. 4d and 4e, in the ULT scenario, 65.4% of the increase in global carbon emissions is due to trade in intermediate goods, and 76.4% of the increase in carbon emissions of other economies excluding China and India comes from the trade of intermediate goods. In the MLT scenarios, similar conclusions hold. For example, in the BM scenario, 72.5% of the increase in global carbon emissions comes from the trade of intermediate goods, and 83.5% of the increase in carbon emissions of other economies excluding China and India comes from the trade of intermediate goods. This indicates that the substitution of intermediate goods by India is the main source of the increase in carbon emissions.

Such a shift would undo years of efforts to cut carbon emissions

Fig. 5 shows the changes in carbon emissions of different economies during the process of India's undertaking of China's industrial relocation. A shocking result was found: in the ultra-long term, the increase in global carbon emissions (855.5 Mt CO2) from India's undertaking of China's industrial relocation exceeds the carbon emission reduction achieved by every G7 country after the Copenhagen Climate Conference (2009-2021), reaching 85.1% of the carbon emission reduction achieved by all G7 economies in the same 12 years. It also exceeds the carbon emission reductions of the EU (472.0 Mt CO2) and part of the G20 (all G20 economies except China and India) (691.1Mt CO2) in the same 12 years, accounting for 77.8% of the total emission reduction by all OECD economies. In the medium and long term, under the BM scenario, the increase in global carbon emissions (396.5 Mt CO2) from India's undertaking of China's industrial relocation exceeds the carbon emission reduction achieved by every G7 economy except the United States after the Copenhagen Climate Conference, equaling 39.4% of the emissions cut by all G7 economies, 84.0%

of the EU reduction, and 36.1% by the OECD reduction over the same 12-year period.

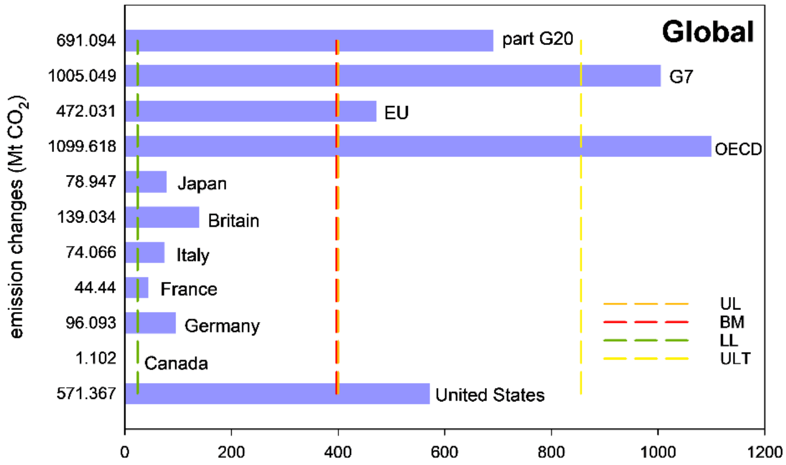

Fig. 5 The impact on carbon emissions in different economies. partG20 represents other G20 economies excluding China and India

For individual economies, we measured the G7 economies which want to be pioneers in climate and environmental protection. As shown in Figure 6a, in the ultra-long term, Canada's carbon emission increase (0.3 Mt CO_2) is more than three times its average annual carbon reduction since the Copenhagen Climate Conference. The United States, Italy, Britain, and Germany each increased their emissions by 15.3%, 8.7%, 4.4%, and 3.1% of their respective average annual reductions since the Copenhagen Climate Conference. In the medium and long term, take the BM scenario as an example, Canada's carbon emission also increase (0.2 Mt CO_2) is more than two times its average annual carbon reduction since the Copenhagen Climate Conference. The United States, Italy, Britain, and Germany each increased their emissions by 8.4%, 2.4%, 1.9%, and 0.3% of their respective average annual reductions since the Copenhagen Climate Conference.

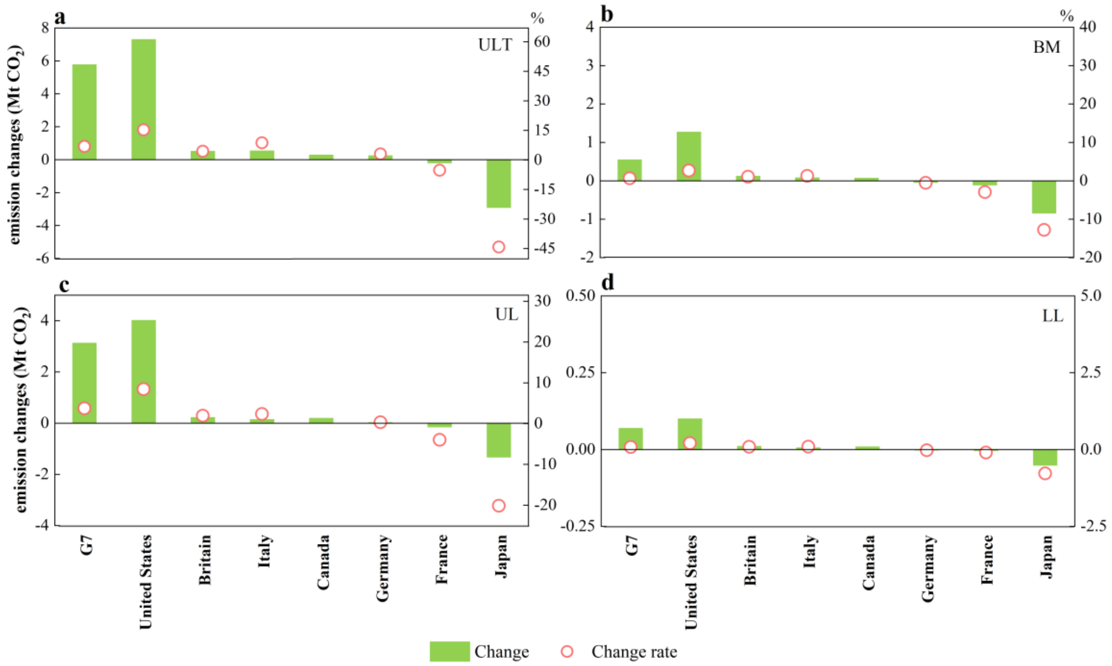

Fig. 6 CO_2 emission burdens for G7 economies. a, b, c, d represent the changes in CO_2 emissions in the G7 economies under the ULT, UL, BM, LL scenarios and their proportions to their annual average emission reduction, respectively.

Sectoral contribution of carbon emissions effects caused by industrial relocation

In the process of India undertaking China's industrial outmigration, substantial sector heterogeneity exists in the environmental impact. Fig.7 illustrates the impact of India's undertaking of China's industrial outmigration on global carbon emissions by sector. The shift of 14 out of 17 manufacturing sectors (in addition to the food, petroleum and chemical industry sectors) has a negative impact on global carbon emissions in both the medium and long term and the ultra-long term.

In the ultra-long term, four sectors - computers, basic metals, electrical equipment and automotives - are the main contributors to the increase in global carbon emissions, accounting for 79.8% of the total increase in carbon emissions caused by industrial relocation in all sectors. In the medium and long term, the transfer of basic metals and automotives are the main sectors that increase global carbon emissions, accounting for 80.5% of the total increase.

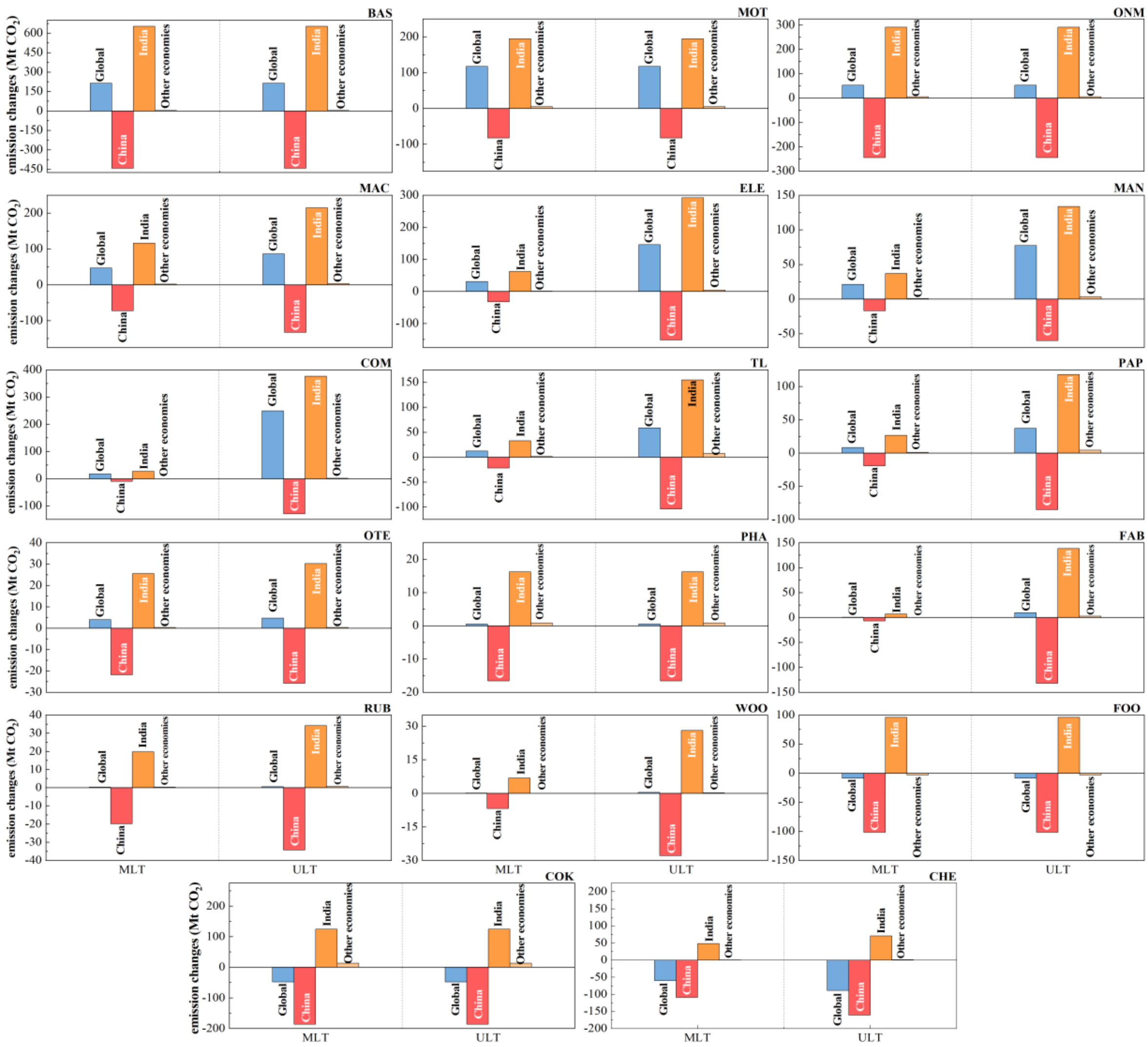

Fig. 7 The carbon emission effect of industrial relocation in different sectors. The names of the sectors in the figure are indicated by abbreviations, and the corresponding table is shown in Supplementary Table 2.

In the ultra-long term, as shown in Fig. 8, the computer, basic metals, electrical equipment, and automotive sectors derive 64.0%, 99.8%, 72.3%, and 46.0% of their carbon emissions, respectively, from the substitution of intermediate goods. Ensuring that the intermediate goods originally imported from China in the computer, basic metals, and electrical equipment sectors, as well as the final goods in the automotive industry, are not substituted by India can reduce the carbon burden in this scenario by 57.4% (523.7 Mt CO_2). In the medium and long term, for the basic metals and automotive sectors, 99.8% and 46.0% of carbon emissions, respectively, come from the substitution of intermediate goods. Thus, preventing the substitution of intermediate goods from China in the basic metals sector and final goods in the automotive industry by India can reduce the carbon burden in this scenario by 67.3% (278.2 Mt CO_2).

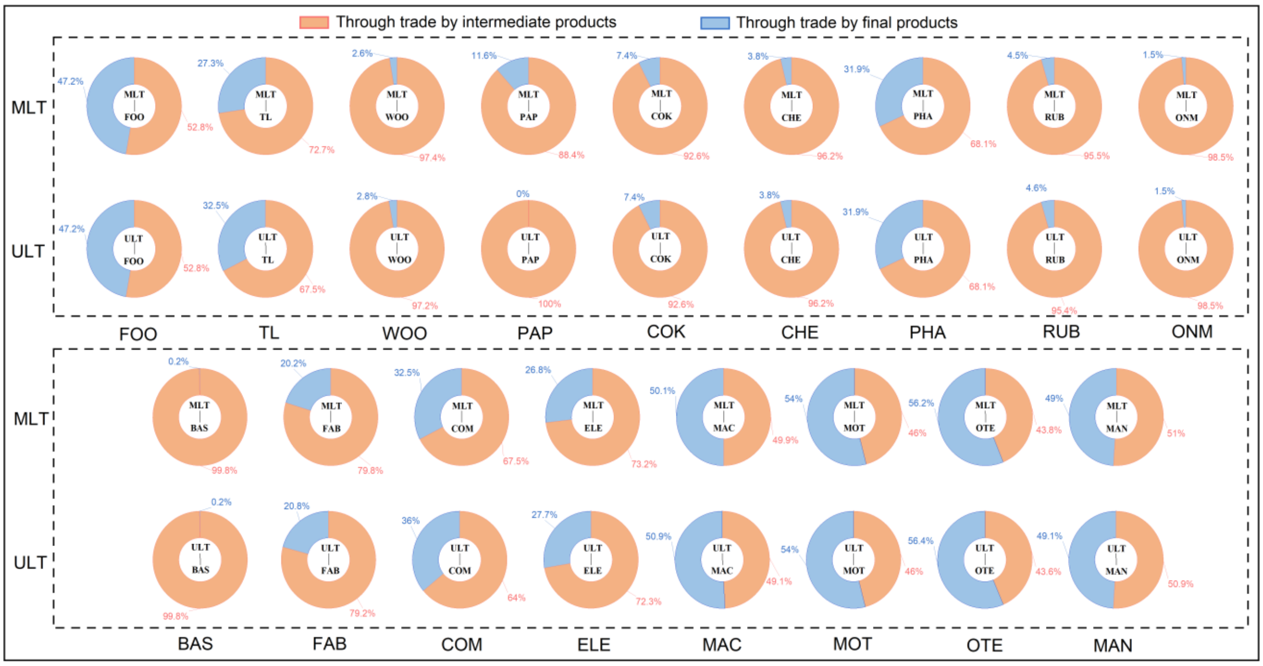

Fig. 8 Source structure of carbon emission effects in different sectors.

Discussion

In the context of global value chain reconstruction, rising labor costs, intensified resource and environmental constraints in China, coupled with geopolitical conflicts, have led to the transfer of labor-intensive industries to emerging economies such as those in Southeast Asia and South Asia. Western developed economies and India itself are actively implementing a series of industrial policies to position India as the main host country for this new wave of international industrial relocation. Since 2019, the Quadruple Alliance (include the United States, Japan, India and Australia) has strengthened its economic collaboration. The US-led Blue Dot Network and Economic Prosperity Network initiatives identify India as a production base for low and medium-end manufacturing to replace Chinese manufacturing. This makes India the most likely economy to undertake China's industrial relocation.

In this paper, we construct a carbon emission accounting model framework for industrial relocation and use counterfactual analysis to estimate the global economic and carbon emission effects of India's undertaking of China's industrial relocation. The results show that this relocation will increase regional and global carbon emissions and reduce global economic growth. The increase in carbon emissions caused by this industrial relocation could undo years of global efforts to cut emissions. While Policies introduced by Western developed countries to support India's development as a manufacturing hub may bring short-term economic benefits, in the long run, they will lead to higher carbon emissions, exacerbate the global climate problem, and reduce global economic growth. Sector-wise, computers, basic metals, electrical equipment, and automotives account for about 80% of the total increase in carbon emissions caused by industrial relocation. In particular, carbon emissions from the computer, basic metal, and electrical equipment sectors are mainly derived from trade in intermediate products, while emissions from the automotive sector come from trade in final products. Thus, ensuring that the intermediate goods originally imported from China in the computer, basic metals, and electrical equipment sectors, as well as the final goods in the automotive sector, are not substituted by India can reduce the carbon burden by more than half. To alleviate the climate crisis and promote sustainable economic development, India should avoid undertaking the outmigration of Chinese industries in the four sectors of computers, basic metals, electrical equipment and automotives. In addition, developing countries in the global South urgently need technological advancements to reduce pollutant intensity. Accelerating the diffusion of cleaner production technologies to Southeast and South Asian countries will help reduce the carbon emission intensity gap with developed countries and subsequently reduce the carbon emissions caused by industrial relocation.

In our study, we assume that the Indian production technology and its corresponding carbon emission efficiency remain constant. On the one hand, as trade patterns change, a country's production technology may also evolve, impacting global and regional emissions. In addition, the promotion and mass-scale adoption of clean energy still face challenges. The IEA's World Energy Outlook 2021 notes that "every data point showing the speed of the energy transition is likely to be offset by another data point showing the stubbornness of traditional energy sources". As India expands production, it is likely to increase its use of traditional energy sources due to their short construction periods, compared to the longer infrastructure development time required for clean energy such as solar and wind. This dependence on fossil fuels in the process of production expansion will likely lead to a further rise in carbon emissions and increased pressure on the global climate. On the other hand, for India to assume the role of a global manufacturing hub, it will require massive investment in infrastructure and fixed assets, which will generate additional carbon emissions Therefore, the impact on regional and global carbon emissions from India's undertaking of China's industrial relocation may be higher than our estimates suggest, warranting future research in this direction. Sector-level calculations show that the computer and automotive sectors are important sources of the increased carbon burden, and these two sectors are also the key industrial sectors for India’s current development. Furthermore, our calculations indicate that the transfer scale of the food industry is relatively large, and its relocation has a positive effect on the global environment. However, recent concerns about food safety in India may result in a smaller scale of food industry relocation than we estimate, potentially increasing the negative impact of this industrial relocation on carbon emissions.

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