Manufacturing Migration and Trade Embodied Carbon Transfer: Empirical Evidence From China and Thailand

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Manufacturing migration and trade embodied carbon transfer: empirical evidence from China and Thailand

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Abstract

At present, China's carbon emissions rank first in the world, which not only brings huge challenges to the sustainable development of China's economy, but also brings more pressure from public opinion in the international community. In 2020, ASEAN has become China's largest trading partner, and Thailand, due to its unique industrial structure and investment environment, will surely become one of the main ASEAN countries to undertake the transfer of China's manufacturing industry. Over the years, the shift of carbon emissions by the continuous transfer of a large number of basic manufacturing industries from China to Thailand promoted the release of China's carbon emission pressure. In this article, on the basis of the data of import and export commodities between China and Thailand from 2012 to 2017, the input-output model is carried out to analyze the energy consumption of China's various industries, and three periods, namely 2012, 2015, and 2017, are used to be key periods to calculate the embodied carbon of China's manufacturing migration and Sino-Thailand trade. The empirical results show that the transfer of China's manufacturing to Thailand from 2012 to 2017 has continued to rise. The transfer of Chinese manufacturing to Thailand is positively correlated with the carbon emissions of trade between the two countries, which has promoted the relief of China's pressure on energy conservation and emission reduction. Therefore, government departments should formulate differentiated and stable domestic manufacturing policies; spend on the development of advanced manufacturing industries with low energy consumption and high technology density; encourage the relocation of industries with low technology density and high

carbon emissions to effectively reduce environmental pressure in China.

Keywords： Manufacturing migration; Trade embodied carbon; Input-output method

Introduction

Research background and significance

After joining WTO, the manufacturing industry and foreign trade develop rapidly in China. In 2009 and 2010, China became the largest exporter and manufacturer all over the world. By the end of 2018, China's manufacturing sector has accounted for about 29.4 percent of GDP and 28.7 percent of global manufacturing. With the rapid development of manufacturing and foreign trade, the environmental and resource pressures have constrained the sustainable development of the industry. In recent years, the overall carbon emissions and carbon transfer from trade have also increased rapidly in China. Since 2006, China has become the world's largest carbon emitter, which has put great pressure on China's efforts to conserve energy, such as carbon emission reduction and environmental protection. Global warming and the continuous decline of environmental carrying capacity further strengthen the total constraint of carbon emissions. For many years, China's basic manufacturing industry has been shifting to Southeast Asian countries, and the study on the impact of the trade changes on carbon emission transfer is of great practical significance.

This paper aims to study the relationship between trade implied carbon transfer and Southeast Asian countries' undertaking of China's manufacturing industry transfer in recent years. Thailand, due to its unique industrial structure, good investment environment and other advantages, has become one of the important ASEAN target countries to undertake the transfer of China's basic manufacturing industry. Therefore, Thailand is selected as a representative country in this paper. In recent years, a large number of investors from China have set up factories in Thailand to transfer the domestic manufacturing industry to Thailand, making full use of Thailand's cheaper human capital and production costs than those of China. The changing trend of Sino-Thai bilateral trade will inevitably have a potential impact on the carbon implicit. This paper is to reveal the relationship between the shift of Chinese manufacturing to Southeast Asia and the carbon implications of trade, which is of great significance for China to solve the environmental problems related to manufacturing trade.

Literature review

Nowadays, it is very common that the manufacturing industry transfer transnationally in the world. The transnational transfer of manufacturing brings about the change of trade flow and the transfer of implicit carbon emission, which attracts much more attention in academia than before. In different periods of manufacturing shift, researchers pay different attention to the carbon implicit in trade. Before 2010, the global manufacturing industry migrated to mainland China, and China's import and export trade led to the increase of the total amount of carbon implied (Jiaoguo Xie, Peishan Jiang, 2014). The distribution and transfer of carbon implied in trade in multiple regions became the focus of research (Tao Wei, Shuijun Peng, 2017). In the field of studies on carbon implicit in trade among different countries, many scholars paid much attention to the calculation of industrial transfer and carbon implicit in trade transfer from the United States and Japan, two major trading partners, to China (Lutong Li, 2015; Nan Chen, Xuemin Liu, Yuichi Nagatabe, 2016); and explained the influence mechanism from the perspective of vertical specialization.

Over the past decade, due to the rising costs such as land, labor and material resources of mainland China, together with the continuous appreciation of the RMB, resulting in the reduction or even disappearance of the advantage of labor-intensive industries in China's manufacturing sector. At the same time, the Chinese mainland constantly implement transnational manufacturing industry transferring, those export-oriented and low-end manufacturing industry began to transfer to Southeast Asian countries, six of which undertake industrial transfer in the front row (Yong Li, 2018). In comparison with other countries, Thailand has a relatively stronger industrial undertaking capacity, better industrial foundation, investment environment and policy welfare, and its domestic upstream and downstream industrial chains that match labor-intensive industries have developed better. Among the "Belt and Road" countries, Thailand is in the first echelon due to its potential to undertake the transfer of manufacturing industries (Xiaotao Zhang, Yi Liu, Cui Yang, 2019).

In 2011, ten ASEAN countries became China's third largest trading partner after the United States and the European Union. Many studies have begun to focus on the carbon implications of trade between China and ASEAN. Existing studies have found that, although China's imports of embodied carbon from ASEAN increase year by year, the growth rate of China's exports of embodied carbon is faster, leading to the disadvantage of China's net export (Huan Yuan, 2019). From the perspective of vertical division of labor, the carbon export implied in East Asia's trade with China gradually decreases (Zhiquan Qian, Laike Yang, 2016), while the carbon export from ASEAN countries to China gradually increases (Hongfei Chen, 2018).

In terms of the measurement of trade embedded carbon, input-output models are adopted in most transnational studies (Yaxiong Zhang, Kun Zhao, Fei Wang, 2010). Among them, multinational input-output model (Multi Regional Input-Output model, hereinafter referred to as the model of MRIO) become an effective analysis tool, which is widely used in several frontier research fields, such as the driving factors of international trade implicit carbon (Rosa Duarte et al., 2018), the domestic provincial carbon emissions reduction mechanism (Qiaoling Liu, et al., 2019) and the regional carbon transfer problem analysis (Hai Xie et al., 2017). MRIO model can not only measure the overall carbon implicit in trade of domestic manufacturing industry (Jiefeng Li, 2017), but also carry out targeted analysis on the carbon implicit in international trade in such regions as Beijing, Tianjin and Hebei (Cong Liu et al. 2017), suggesting that this tool has a strong applicability. This paper intends to use the MRIO method to study the carbon implications of trade caused by the relocation of Chinese manufacturing to Thailand.

From the above studies, it can be found that the current academic achievements on the issue of carbon implicit in trade are mostly focused on the impact of the transfer of the world manufacturing to China, and there are few studies on the impact of the transfer of Chinese manufacturing on carbon implicit in trade. At present, more and more manufacturing industries in mainland China begin to transfer to foreign countries, and this trend is so obvious that it cannot be underestimated. The large-scale transfer of the middle and low-end manufacturing industries to Southeast Asia will certainly lead to a large number of changes in the flow direction of the carbon implied in trade. Therefore, it is of great significance to calculate the carbon hidden in China as well as the related impact of industrial upgrading. Thailand is a typical Southeast Asian country to undertake the outmigration of Chinese manufacturing. Using MRIO model, this paper focuses on Sino-Thai trade carbon transfer problems caused by the transfer of manufacturing industry. We expect to enrich the existing trade carbon transfer empirical results in the study of nationality, and to reveal carbon emissions in the process of outsourcing manufacturing change of import and export structure. To bring about industrial upgrading, promote energy conservation and emissions reduction, China will adjust and implement the policy to achieve a high quality of development.

Related theory and mechanism analysis

Carbon implicit in trade

The concept of "trade-embodied carbon" originates from the International Federation of Research Institutions. In 1974, "trade-implied carbon" was used for the first time in the Energy Working Group Meeting to express the total amount of resources consumed in the process of production activities. The energy or pollutants emissions are combined with the "embodied" words to evaluate the energy consumption or pollution emitted directly or indirectly during the production of goods or services. Specifically, in the field of carbon emissions, because any production will directly or indirectly produce carbon emissions, the concept of "hidden carbon" is derived, which is used to measure the total amount of carbon dioxide emitted in the process of the production of goods or services. Among the influencing factors of the change of implicit carbon emissions, the energy consumption effect is the main factor to reduce the implicit carbon emissions of exports. Because of the lowest energy consumption effect, the large-scale transfer of manufacturing industry in China to other countries is bound to have a significant impact on the total energy consumption.

Commodity trade in international trade activities divides the various links of the entire chain of commodity production into an international division of labor, resulting in a spatial spanning between production links, as well as space between production and consumption. Therefore, carbon emissions can be understood from the perspectives of production and consumption. The carbon emission measurement in a region or a country is generally measured from the perspectives of production and consumption. The production angle measure refers to the total carbon emissions of commodities produced by a region or a country, while the consumer angle measure refers to the total carbon emissions generated at home and abroad during the process of producing a final consumer product from the beginning to the end.

The carbon emissions from the beginning to the end of production are the total carbon emissions of all productive organizations in economic activities within the territory of a country. However, in the context of such close global division of labor and cooperation, most commodity production is carried out across borders. In global trade, such a measurement method makes the carbon footprint go beyond the borders of the country, which is obviously unfair. Therefore, this paper mainly calculates carbon emissions from the perspective of domestic consumption. Carbon emissions are calculated as follows:

$$\text{Carbon emissions} = \text{carbon emissions produced} + \text{carbon emissions imported} - \text{carbon emissions exported} \quad (1)$$

Trade embodied carbon has always been linked to goods trading which can also be regarded as tangible commodity trading. Goods trading are based on real goods, which will bring about the corresponding carbon emissions in the process of its production. These goods are consumed in another country through transnational trading, which makes the carbon emissions be transferred from producing countries to consumption countries. Commodity producing countries not only suffer from the deterioration of environmental pollution caused by commodity production, but also undergo the damage of international image, and bear more pressure from international public opinions.

In the process of global trade, due to the differences in technological level and industrial base, most developed countries are in the upper reaches of the industrial chain and in the leading position of science and technology. They often produce low-emission products and import high-emission commodities, thus taking a dominant position in global trade of commodities. Developing countries, which are in the downstream of the industrial chain, do not have enough advanced science and technology to support the production of low-carbon products. Instead, they can only produce and export high-carbon products in large quantities, which bear considerable pressure of carbon emissions and undertake a large amount of trade implied carbon transferred from developed countries in the process of international trade. By the same token, China is also shouldering the burden of carbon emissions that should be borne by developed countries. Therefore, under the background of economic globalization, it is particularly important to carry out related research on the transfer of implied carbon to define China's responsibility in global carbon emissions.

Transfer of manufacturing industries

By reviewing the absolute scale of global manufacturing value-added from 1965 to 2010, the distribution pattern among countries and the changing trend, it can be found that the distribution of global production chain of the world's manufacturing industry is in a continuous evolution process, and its development can be roughly divided into two stages:

1) The first manufacturing shift took place in the 1970s, mainly from the US to overseas. In the first oil crisis, many domestic manufacturing enterprises in the United States were in the stage of marginal decline of industrial competitive advantage, and the production cost increased greatly. Japan, South Korea, Taiwan and other regions have more cost advantages, and the rapid development of these emerging industrial economies after the war led to the transfer of a large number of general manufacturing industries from the United States to Japan, South Korea and other countries. Take Japan as an example. From the postwar period to the 1980s, Japan completed the transformation from undertaking the light and textile industry to the heavy chemical industry, and then to the machinery industry, transportation equipment manufacturing, and durable consumer goods. Between 1965 and 1975, the average growth rate of industrial added value of the manufacturing in Japan was close to 17.90%, which was about 10 percentage points higher than that of the United States on average. By 1975, the added value of manufacturing in Japan had surpassed Western European countries and reached one third of that of the United States.

2) The second manufacturing transferring took place around 1990, mainly shifted from the United States, Japan and South Korea to the Chinese mainland. China's reform and development since 1978 has attracted a large number of textile industries from Hong Kong, Macao, Taiwan, Japan and South Korea; in 1992, after Comrade Deng Xiaoping made a speech on his southern tour, we

further expanded the industrial field and spatial scope of opening-up. After the 1997 Asian financial crisis, China's stable market and low cost drawed a large number of European and American electronics and equipment manufacturers. From 1997 to 2010, the average growth rate of the manufacturing industry in the Chinese mainland reached 10.06%, which is much faster than that of developed countries in Europe and the United States. The value added of the manufacturing sector also increased from 7.47% to 18.39%, also far ahead of that of the United States, Japan.

After long-term development of China's manufacturing industry, since 2010, especially since 2012, the labor force upgrade has led to the continuous increase of production costs, and a large number of manufacturing industries have moved to Southeast Asia with lower production costs. Southeast Asian countries have become the new regions for the transfer of manufacturing industries. From the manufacturing added value of major Southeast Asian countries from 2010 to 2017 (Table 1), it can be seen that in recent years, the manufacturing added value of Southeast Asian countries has seen a huge growth compared with that in previous years, and most countries have seen multiple growth compared with 2010, which can be seen the achievements of these Southeast Asian countries to undertake the transfer of manufacturing industry in these years.

Table 1 Major Southeast Asian Countries 2010-2017 Manufacturing Value Added (Unit: US $100 million)

	Country/Year	The Philippines	Vietnam	Thailand	Cambodia	Malaysia	Indonesia	Myanmar	Bangladesh
Manufacturing added value	2010	198	57. 5	361. 4	5. 9	289. 5	373. 9	6. 4	74. 9
	2017	691	342	1232. 2	35. 9	701. 6	2047. 3	164	432

Analysis on the current situation of manufacturing transfer between China and Thailand

Among the ten ASEAN countries, Thailand is a typical country with stable diplomatic relations and close economic and trade exchanges with China. Since the establishment of diplomatic ties between China and Thailand more than 40 years ago, China and Thailand have maintained friendly relations, during which China's direct investment in Thailand has also been increasing and the level of bilateral cooperation has been deepening. From 2012 to 2017, investment projects and investment amount have been on the rise, basically showing a steady upward trend（Figure 1）. The number of Chinese investment projects in Thailand increased from 26 in 2007 to 252 in 2016, and the direct investment also reached 4.735 billion US dollars. Among them, 152 projects from 2012 to 2016 accounted for 60.3% of the total number of projects in the past three decades, and the investment amount reached 2.703 billion US dollars, accounting for 57.36% of the total investment in the past ten years.

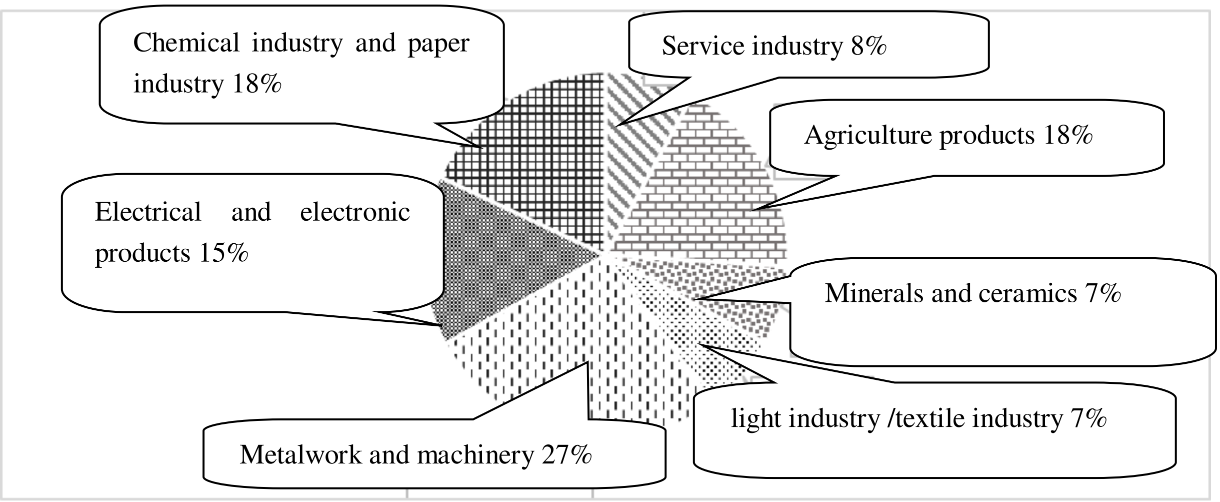

Figure 1 Industrial structure of China's investment projects in Thailand from 2012-2017 ,

The investment projects mainly focus on the manufacturing industry, mainly in the electronic and electrical industry, machinery, metal products, textile industry and light industry, paper products, chemical products, plastic products, *etc*. The manufacturing sector accounted for 74 percent of the investment(Table2). It can be seen that China's investment in Thailand is mainly the transfer of manufacturing industry, and China's investment in Thailand's manufacturing industry is on the rise.

Table 2 China's investment in Thailand's manufacturing industry from 2007 to 2016

year	Number of items	Approved Project Amount ($100 million)	Actual investment amount ($100 million)
2007	26	537. 57	11. 03
2008	17	108. 88	
2009	15	219. 36	25. 15
2010	28	541. 83	67. 86
2011	31	601. 58	88. 7
2012	28	508. 52	56. 41
2013	27	476. 35	30. 27
2014	30	532. 15	38. 37
2015	33	591. 41	31. 31
2016	34	594. 9	36. 56

Source: Investment Promotion Council of Thailand

Input-output model construction

The input-output model is built on the basis of the input-output table. In this paper, the annual input-output table of a country or region is taken as the standard. The input-output table takes money as the unit of measurement and divides the economic system of a country or region into different production sectors. The input-output table reflects the actual movement process of commodities or factors of production among various production departments, and describes the flow process and defense of value among various production departments. Table 3 is a standard input-output table:

Table 3 Input and output table

<table>
<tr><td colspan="2" rowspan="3">Input and output</td><td colspan="5">Use among</td><td colspan="7">Finally using</td><td rowspan="3">Total output</td></tr>
<tr><td rowspan="2">Department of a</td><td rowspan="2">Department of b</td><td rowspan="2">. . .</td><td rowspan="2">Department of x</td><td rowspan="2">Intermediate service total</td><td colspan="3">Final consumption</td><td colspan="2">Gross capital formation</td><td rowspan="2">export</td><td rowspan="2">import</td></tr>
<tr><td>Consumption of rural residents</td><td>Consumption of urban residents</td><td>Government consumption</td><td>Total fixed capital formation</td><td>Inventory increase</td></tr>
<tr><td rowspan="4">Intermediate input</td><td>Department of a</td><td colspan="5" rowspan="4">By the intermediate input and intermediate output is poor composition, there are two meanings, the horizontal look represents the input of a department to another department, and the vertical is the consumption of the production of a certain part to another department.</td><td colspan="8" rowspan="4">It is composed of intermediate input and poor final use, including four sectors of final use, import and total output in the vertical direction, and intermediate input of various departments in the horizontal direction. It's also called the final demand matrix.</td></tr>
<tr><td>Department of b</td></tr>
<tr><td>. . .</td></tr>
<tr><td>Department of x</td></tr>
<tr><td rowspan="3">The added value of</td><td>Labor compensation</td><td colspan="5" rowspan="3">The total input matrix is composed of rows added value and columns of various sectors of national economy.</td><td colspan="8" rowspan="3"></td></tr>
<tr><td>. . .</td></tr>
<tr><td>Total added value</td></tr>
<tr><td colspan="2">The total investment</td><td colspan="13"></td></tr>
</table>

After sorting out and cleaning all the data in the input-output table (see Table 4), it can be seen that the synthesis of intermediate input, use and final use is the total output.

Table 4 Data cleaning of input-output table

Input and output		Use among					Finally using	Total output
		Department of a	Unit 2	. . .	Department of n	Intermediate service total		
Intermediate input	Department of a	X_{11}	X_{12}	,	X_{1n}	E_1	y_1	X_1
	Unit 2	X_{21}	X_{22}	,	X_{2n}	E_2	y_2	X_2
	. . .	,	,	,	,	,	,	,
	Department of n	X_{n1}	X_{n2}	,	X_{nn}	E_n	y_n	X_n
	subtotal	C_1	C_2	,	C_n	C	Y	X
The added value of	Labor compensation	V_1	V_2	,	V_n	V		
	Total added value	N_1	N_2	,	N_n	N		
The total investment								

According to the data model established in the above table, the following equations can be obtained:

$$\begin{cases} X_{11} + X_{21} + \cdots + X_{1n} + y_1 = X_1 \\ X_{21} + X_{22} + \cdots + X_{2n} + y_2 = X_2 \\ \cdots\cdots\cdots\cdots \\ X_{n1} + X_{n2} + \cdots + X_{nn} + y_n = X_n \end{cases} \quad (2)$$

In this paper, the equations are simplified to obtain Equation (3):

$$\sum_{j=1}^{n} X_{ij} + y_i = X_i \quad (3)$$

Then, the direct consumption coefficient can be expressed by formula, and Formula (4) can be obtained:

$$\partial IJ = \frac{x_{ij}}{x_j} (\mathrm{I}, \mathrm{j} = 1,2, \cdots, \mathrm{n})$$

Through Equation 3-3, it can be expressed as Equation (5):

$$\sum_{j=1}^{n} \partial_{ij} x_j + y_i = x_i \quad (5)$$

After establishing the above formula, it can be expressed as matrix formula:

$$X = [\mathrm{x}_1, \mathrm{x}_2, \cdots, \mathrm{x}_n] \quad (6)$$

$$y = [\mathrm{y}_1, \mathrm{y}_2, \cdots, \mathrm{y}_n]^T \quad (7)$$

$$\mathrm{A} = \begin{bmatrix} a_{11} \cdots a_{1n} \\ \cdots\cdots\cdots\cdots \\ a_{n1} \cdots a_{nn} \end{bmatrix} \quad (8)$$

Finally, the matrix form is expressed as a system of equations, and the following formula is obtained:

$$AX + Y = X \quad (9)$$

$$(1\text{-}A)X = Y \quad (10)$$

After the above formula is obtained, the first assumption is made:

$$(I - A)X \neq 0$$

Formula (11) can be known as:

$$X = (I - A)^{-1} Y \quad (11)$$

Formula (12) can be obtained:

$$(I-A)-1=B=\begin{bmatrix} B_{11}\cdots B_{1n} \\ \cdots \quad\quad \cdots\cdot \\ B_{n1}\cdots B_{nn} \end{bmatrix} \quad (12)$$

Derived from the above formula, the matrix B of Formula (12) is the complete demand matrix, B in the B matrix$_{ij.}$ It is the complete demand coefficient. The complete demand coefficient means that the products of a unit of J department need to pass a certain number of products of I department, that is, the theoretical interpretation of input and output data. It is the basis for the calculation and research of implicit carbon emissions, and it is of great significance for research.

In this paper, M_i represents the value of export commodity I; Use theta. $_i$Is the carbon emission of a unit of product I in the whole process; C_{ij} represents the implied carbon export volume brought by export product I. Thus, Equation (13) can be obtained:

$$C_i=\sum_{i=1}^{n} \quad M_i\cdot\theta_i \quad (13)$$

In the calculation of carbon implicit in trade, the carbon emissions of exported products in the production process are mainly composed of direct carbon emissions and indirect carbon emissions. In direct carbon emission coefficient calculation,$\theta m1$ Is the direct carbon emission coefficient of department M,$f m$Is the energy emission coefficient of department m,$e m1$Is the energy consumption generated by unit product output value in the production of department M; Equation (14) can be obtained:

$$\theta_{mi}=f_m\cdot e_{m1} \quad (14)$$

Secondly, Formula (15) can be obtained:$\boldsymbol{e_{m1}}=\frac{E_m}{X_m}$

The carbon emission coefficient of energy I in the production process of sector M is denoted by αI, diIs the energy consumption quantity of energy I in the production process of department m; DM represents the total amount of energy consumed by sector M. Thus, Equation (16) can be obtained:

$$F_{\boldsymbol{m}}=\sum_{i=1}^{n}\cdot\alpha_{\boldsymbol{i}}\frac{d_i}{D_m} \quad (16)$$

Indirect carbon emission coefficient calculation, this paper will $\theta m2$I$_s$ the direct carbon emission coefficient of department m; $e m2$Is the indirect energy consumption generated by unit product output value in the production of department M, b_{ij}Is the complete consumption coefficient of department m, and the formula for calculating indirect carbon emission coefficient can be obtained by kneading output analysis:

$$\theta_{m2} = f_m \cdot e_{m2} \tag{17}$$

$$e_{m2} = \sum_{i=1}^{n} \cdot e_{m1} \cdot b_{ij} \tag{18}$$

Finally, the complete carbon emission coefficient θ_m is expressed as Equation (19):

$$\theta_m = \theta_{m1} + \theta_{m2} \tag{19}$$

Estimation of carbon implicit in trade

Sample selection and data sources

This paper studies the impact of manufacturing transfer on carbon transfer implied in trade between China and Thailand. The trade data and energy data are obtained from the National Bureau of Statistics of China and the Economic Management Family database. In the input-output table of China, the input-output table of three benchmark years of National Bureau of Statistics (2012, 2015 and 2017) is adopted. The energy consumption table of all industries in China adopts the energy consumption table of the National Bureau of Statistics for the three benchmark years of 2012, 2015 and 2017. The data of National Bureau of Statistics from 2012 to 2017 was used in the table of China's import and export commodities to Thailand.

Data processing and measurement

Calculation of Implied Carbon Emission of Imports

The method and formula of import implied carbon emissions are the same as those in the previous input-output model section. The calculation formula is as follows:

$$C_i = \sum_{i=1}^{n} \quad M_i \cdot \theta_i \tag{20}$$

Although the calculation formula for the embodied carbon emissions of imports is the same, there are two paradigms: the first one is set as the embodied carbon of the first category of goods exported from Thailand to China $i\,C_i$, the implied carbon emission coefficient of the second sector in

Thailand is $i\theta_i$, the trade volume of category I commodities exported from Thailand to China is iM_i;In the second case, the implicit carbon of Thailand's exports to China is set as iC_i, the implied carbon emission coefficient of China's domestic sector of the second category is $i\theta_i$, the trade volume of category I commodities exported from Thailand to China is iM_i.

The former method uses the input-output ratio and energy consumption of the exporting country to calculate the carbon implicit in China's trade in export goods. The measurement results of this method will be relatively accurate, but it needs to use the input-output table and energy consumption table of Thailand, and conduct the same data sorting according to the classification of industry sectors in Thailand. Inconsistency in industry classification between China and Thailand will lead to large errors. At the same time, the input-output table of Thailand needs to be prepared, and the data collation conducted when calculating the data of China needs to be repeated. Therefore, this paper chooses the second method, replacing the carbon emission coefficient of each sector in Thailand with the carbon emission coefficient of each sector in China, which makes the calculation simpler and the data accuracy can be guaranteed.

Data processing and measurement

(1) Energy carbon emission coefficient

According to the calculation formula deduced above, the energy carbon emission coefficient is determined according to the proportion of various energy quantities consumed by each department. The main sources of CO_2 generation are coal, oil and natural gas. According to China Statistical Yearbook, the energy proportion of coal, oil and natural gas can be calculated respectively (coal, oil and natural gas are converted into standard coal). According to the following table (Table 5), the energy emission coefficients of coal, oil and natural gas can be obtained.

Table 5 Energy substance emission coefficient table

Table of emission coefficient of energy substances	
Energy material	Emission coefficient (unit: ton CO_2/ ten thousand tons)
coal	2. 66
oil	2. 13
Natural gas	1. 50

The data comes from the National Bureau of Statistics

(2) Department adjustment

When performing data statistics and calculations, because there are too many department classifications on the input-output table, in order to maintain the consistency of the data and enhance the rationality of the statistical data, the relevant departments are organized without affecting the core conclusions in this study. Under the premise of not affecting the core conclusions of this article, the relevant departments are sorted out, and only the data of manufacturing-related departments are included in a targeted manner, and some departments that do not have trade volume are deleted. Some reasonable adjustments in each production department were made to obtain classified statistics for each department (Table 6).

Table 6 Department classification table of China and Thailand

The serial number	department	The serial number	department
1	Oil and gas extraction products	9	Metal smelting and calendaring products
2	Food and tobacco	10	Metal products
3	textile	11	Special equipment
4	Textile, clothing, shoes, hats, leather, down and their products	12	Electrical machinery and equipment
5	Wood products and furniture	13	Communication equipment, computers and other electronic equipment
6	Paper printing and cultural and educational sports goods	14	Instrument and meter
7	Petroleum, coking products and processed nuclear fuel products	15	Scrap waste
8	Chemical products	16	Production and supply of electricity and heat

Firstly, the energy consumption EM1 per unit output value was calculated according to Equation (15), and the energy carbon emission coefficient of different sectors was acquired on the basis of Equation (16) according to the energy substance emission coefficient in Table 7, and the energy consumption data of Thailand was estimated in accordance with the description of the transfer of embodied carbon emissions from imported goods in the data processing.

Secondly, the direct carbon emission coefficient is calculated according to Equation (14)θ_{mi}, the indirect carbon emission coefficient is calculated according to Equations (17) and (18)θ_{m2}.

Thirdly, the total carbon emission coefficient is calculated by adding the direct carbon emission coefficient and the indirect carbon emission coefficient according to Equation (19)θ. The complete carbon emission coefficient includes the direct and indirect emission coefficients and the carbon emission coefficients of China and Thailand's import and export (Table 7):

Table 7 Table of complete carbon emission coefficient by sector

The serial number	department	2012	2015	2017
1	Oil and gas extraction products	1. 5429	1. 0362	3. 7245
2	Food and tobacco	1. 3885	2. 0002	0. 6646
3	textile	1. 8335	1. 8945	1. 5274
4	Textile, clothing, shoes, hats, leather, down and their products	0. 3106	0. 4029	0. 3135
5	Wood products and furniture	0. 7046	0. 7386	0. 6869
6	Paper printing and cultural and educational sports goods	0. 8523	0. 9858	0. 6544
7	Petroleum, coking products and processed nuclear fuel products	1. 4933	1. 4683	1. 0232
8	Chemical products	4. 6914	5. 0369	1. 5599
9	Metal smelting and calendaring products	4. 0246	3. 7389	1. 2490
10	Metal products	0. 8281	0. 9278	0. 5675
11	Special equipment	0. 5322	0. 6345	0. 6131
12	Electrical machinery and equipment	1. 0098	1. 2469	0. 7075
13	Communication equipment, computers and other electronic equipment	2. 2305	2. 4394	1. 3983
14	Instrument and meter	0. 3732	0. 3915	1. 2069
15	Scrap waste	0. 3554	0. 3767	2. 6687
16	Production and supply of electricity and heat	2. 3611	2. 8501	1. 4797

According to the energy consumption data of Thailand, $F_m = (EM/EZ)*F$ is used to calculate the energy consumption data, and the three steps above are followed to complete the calculation. Finally, the statistical table of the implied carbon emissions of China's trade with Thailand in 2012, 2015 and 2017 is obtained:

Table 8 Statistical table of carbon emissions implied in China's trade with Thailand in 2012, 2015 and 2017

The serial number	department	2012		2015		2017	
		import	export	import	export	import	export
1	Petroleum and natural gas exploration and exploitation	9. 54	0. 00	9. 88	0. 00	11. 19	0. 00
2	Food and Tobacco Manufacturing	18. 34	0. 00	24. 27	0. 00	29. 66	0. 00
3	Textile industry	10. 20	106. 98	8. 39	98. 05	8. 23	107. 24
4	Textile, clothing, footwear and headgear industry	0. 00	16. 97	0. 00	21. 82	0. 00	24. 59
5	Wood processing and home furnishing manufacturing	0. 00	15. 18	0. 00	21. 83	0. 00	27. 07
6	Paper making, printing and sports and sports goods manufacturing	5. 09	14. 30	6. 71	16. 62	8. 39	18. 07
7	Petroleum processing, coking and nuclear fuel processing industries	224. 67	0. 00	174. 95	0. 00	0. 00	176. 92
8	The chemical industry	1204. 59	567. 92	870. 50	680. 26	871. 60	846. 90
9	Metal smelting and rolling industry	37. 97	669. 63	75. 57	692. 53	99. 39	726. 08

10	Metal products	17. 05	63. 91	6. 08	80. 17	6. 68	98. 58
11	Special equipment manufacturing	41. 04	28. 42	30. 69	22. 56	28. 72	18. 87
12	Electrical machinery and equipment manufacturing	37. 17	139. 38	49. 77	177. 07	58. 45	207. 35
13	Manufacturing of communications equipment, computers and other electronic equipment	15. 87	204. 80	14. 75	207. 35	17. 80	221. 93
14	Instrumentation and culture, office machinery manufacturing	0. 00	114. 13	0. 00	81. 78	0. 00	77. 19
15	Recycling and other manufacturing	0. 00	6. 05	0. 00	7. 00	0. 00	7. 58
16	The production and supply of electricity and heat	0. 00	75. 70	0. 00	105. 68	0. 00	132. 59

Results Unit (10,000 tons)

Analysis of measurement results

This paper studies the impact of manufacturing industry transfer on the carbon implied in China-Thailand trade. Based on the data of China's direct investment in Thailand from 2012 to 2017 (the website of the National Bureau of Statistics), this paper measures China's direct investment in Thailand to measure the transfer of China to Thailand. In China's outbound investment, it is mainly the transfer of manufacturing industry, so direct investment can be regarded as manufacturing investment (Table 9).

Table 9 China's investment in Thailand

	In 2012,	In 2013,	In 2014,	In 2015,	In 2016,	In 2017,
China's Net Direct Investment in Thailand (US $10,000)	47860	75519	83946	40724	112169	105759

Looking at the total carbon emission coefficient table of the sub-sector of China-Thailand trade:

Table 10 Total carbon emission coefficient of China-Thailand trade

	2012	2015	2017
Full carbon emission factor	24. 53	26. 17	20. 05

Finally, the annual total of carbon emissions can be obtained as follows:

Table 11 China's annual carbon emissions

	2012	2015	2017
Total carbon emissions (unit: 10,000 tons)	506150. 00	598219. 80	608608. 86

It can be observed that China’s investment in Thailand showed a sharp upward trend from 2012 to 2017 (Table 9-Table 11). The complete carbon emission factor fell from 24.53 in 2012 to 20.05 in 2017, indicating that China’s manufacturing trade implied carbon emissions and the energy consumed per unit of carbon emissions is declining, while China’s carbon emissions have increased significantly during 2012-2015, but have a small increase during 2015-2017. In comparison with the full carbon emission coefficient during 2012-2015, the transfer of manufacturing industry is in its infancy stage, which has an impact on the embodied carbon of trade, but the impact is limited. A clear difference can be seen from 2015 to 2017. There has been no significant increase in carbon emissions during the three years, indicating that the transfer of manufacturing at this stage has implications for trade. The carbon-containing shift has a greater impact. Thailand's domestic carbon emissions have risen, and it has assumed the embodied carbon shift from China's trade. On the whole, it can be witnessed that the transfer of manufacturing industry has a clear promotion effect on the transfer of embodied carbon in trade between China and Thailand.

Impact of manufacturing shift on carbon implicit in trade

From the above analysis, it can be seen that there was a large number of manufacturing transfers between China and Thailand in 2012-2017. In all industries, carbon emissions are mainly generated by the manufacturing operations, and the manufacturing industry has undertaken a large amount of carbon emissions. Although the amount of embodied carbon generated in China's trade with Thailand is rising, the upward trend is slowing down. Among them, although China's manufacturing industry is in a trend of outward transfer, there is still a certain amount of domestic development, and the large amount of carbon emission growth that should have existed in the development process disappeared because the transfer of this part of the embodied carbon emissions to Thailand was undertaken by Thailand due to the transfer of manufacturing. Observing the changes in the fully implied carbon emission coefficient, it can be found that the decrease from 24.53 in 2012 to 20.04 in 2017, indicating that, in the trade of goods between China and Thailand, the energy consumed by China to produce a unit of goods is declining, and the carbon emissions produced are also declining. The intermediate part of this is transferred to Thailand, which was undertaken by Thailand (Table 8 - Table 10).

In comparative analysis of embodied carbon emissions between Sino-Thai trade, we removed sectors without import or export, and selected industries such as textile industry, papermaking and printing, stationery and sports goods manufacturing, chemical industry, metal products industry, equipment manufacturing, electrical machinery and equipment manufacturing, communications equipment, computers and other electronic equipment manufacturing industries.

Obviously, it can be found that trade embodied carbon emissions are mainly concentrated in the chemical industry and the metal smelting and processing industry. From the perspective of other major manufacturing industries transferred, the textile industry and other manufacturing data indicated that there was a significant increase in export embodied carbon emissions during 2012-2015, but this rising trend has slowed down during 2015-2017, while imported embodied carbon has shown a downward trend during 2012-2015 and a stable state during 2015-2017. This reflects that China’s responsibility for carbon emissions outside its own country is decreasing. The intermediate input imported by the manufacturing industry transferred from the country directly reaches Thailand. The carbon emissions were decreased, making China more able to handle its international carbon emissions responsibilities.

In combination with China’s transfer of manufacturing industries to Thailand, the trade embodied carbon is beneficial to China in the process of manufacturing transfer, which reduces the pressure of environmental pollution to a certain extent in China. Additionally, trade embodied carbon has a significant positive effect on China’s environmental protection. The changes in trade embodied carbon confirmed that China’s manufacturing shift also has a positive impact on the decline of domestic trade embodied carbon, and alleviates the pressure on China’s total carbon emissions. This provides a reference for China to formulate new policies on trade and investment in the context of the transfer of manufacturing industries overseas, and also provides evidence for China's efforts to reduce carbon emissions due to huge carbon emissions pressures.

Conclusions and recommendations

This paper uses the input-output model to calculate the carbon implicit in trade, and studies the change of the carbon implicit in trade under the situation of manufacturing transfer between China and Thailand. After the analysis of manufacturing transfer first, and then to trade implied in the number of carbon and discharge coefficient calculation and comparison analysis, we found that between 2012 and 2017, China's manufacturing industry transferred to Thailand is in a rising state, part of the transfer of light industry and heavy industry had a significant effect on the implied trade between the two countries. Although China is still in the period of net transference of trade embodied carbon, the carbon emission embodied in export trade is far greater than that embodied in import trade. This situation has created enormous pressure on China's sustainable economic development of energy conservation and emission reduction. In this paper, by means of measuring the carbon emissions implied in the trade between China and Thailand, and making a comparative analysis of the transfer of manufacturing industry, we tried to provide an effective reference for China to formulate foreign trade and investment policies through the data, and to improve the quantitative basis for China to reduce the carbon emission responsibility due to the huge export.

First of all, the carbon emissions embodied in China's trade with Thailand changed with the shift of manufacturing industry, which not only slows down the rising trend of China's carbon emissions embodied in trade, but also eases the pressure of China's energy conservation and emission reduction. On the whole, the transfer of Chinese manufacturing to Thailand is positively correlated with the carbon emissions embodied in trade between the two countries, but the total carbon emissions embodied in trade is in a slowing trend, reflecting that the transfer of manufacturing slows down the growth of the carbon emissions embodied in trade between the two countries. This phenomenon is also closely related to the policies between the two countries. China's increasingly strict energy-saving and emission reduction policies require enterprises to reduce emissions, while Thailand's relatively loose environmental policies and abundant labor resources create favorable conditions for the transfer of China's manufacturing industry, thus exerting an impact on the transfer of carbon implied in trade.

Second, China's shift to Thailand's manufacturing industry is mainly concentrated in industries prone to carbon emission pressure and with low technical requirements. These sectors account for the majority of China's direct investment in Thailand; light manufacturing is a major transfer sector, but it is not a low emission sector in terms of carbon emissions. The largest slowdown in the growth of carbon implicit in trade between the two countries is also in the light manufacturing industry, which has a major impact on the carbon implicit in trade between the two countries.

Finally, although the transfer of manufacturing has a positive impact on China’s environmental pressures, manufacturing is still China’s most important industrial sector and a pillar industry for China’s economic development. With the shift of manufacturing to Southeast Asia, Chinese government should formulate policies to maintain the stability of domestic manufacturing and support China’s outstanding manufacturing enterprises. The calculation results of Sino-Thai trade embodied carbon also help China formulate trade and investment facilitation policies for Southeast Asian countries. The international transfer of manufacturing is a challenge as well as an opportunity. The trend of further transfer of manufacturing in the future will inevitably have a huge economic and political impact on China and the undertaking country. However, China will gradually benefit from the gradual decline in the pressure of international environmental responsibility as the manufacturing industry moves abroad, which brings hope to China's energy conservation and emission reduction work, and is also more conducive to China's high-quality economic growth.

Data Availability

In this article, used to gnap database ,on the basis of the data of import and export commodities between China and Thailand from 2012 to 2017, the input-output model is carried out to analyze the energy consumption of China's various industries, and three periods, namely 2012, 2015, and 2017, are used to be key periods to calculate the embodied carbon of China's manufacturing migration and Sino-Thailand trade.

Declarations

This study was purely registry based, as no human participants were recruited or included in experiments.

Ethics Approval ethics approval is not required for this paper.

Consent to participate Not applicable.

Consent for publication Not applicable.

Authors Contributions WU, and CUI developed the idea of the study, MEI, XU and ZHANG participated in its design and coordination and helped to draft the manuscript. WU and CUI contributed to the acquisition and interpretation of data. WU and CUI provided critical review and substantially revised the manuscript. All authors read and approved the final manuscript.

Competing interests The authors declare no competing interests.

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Figures

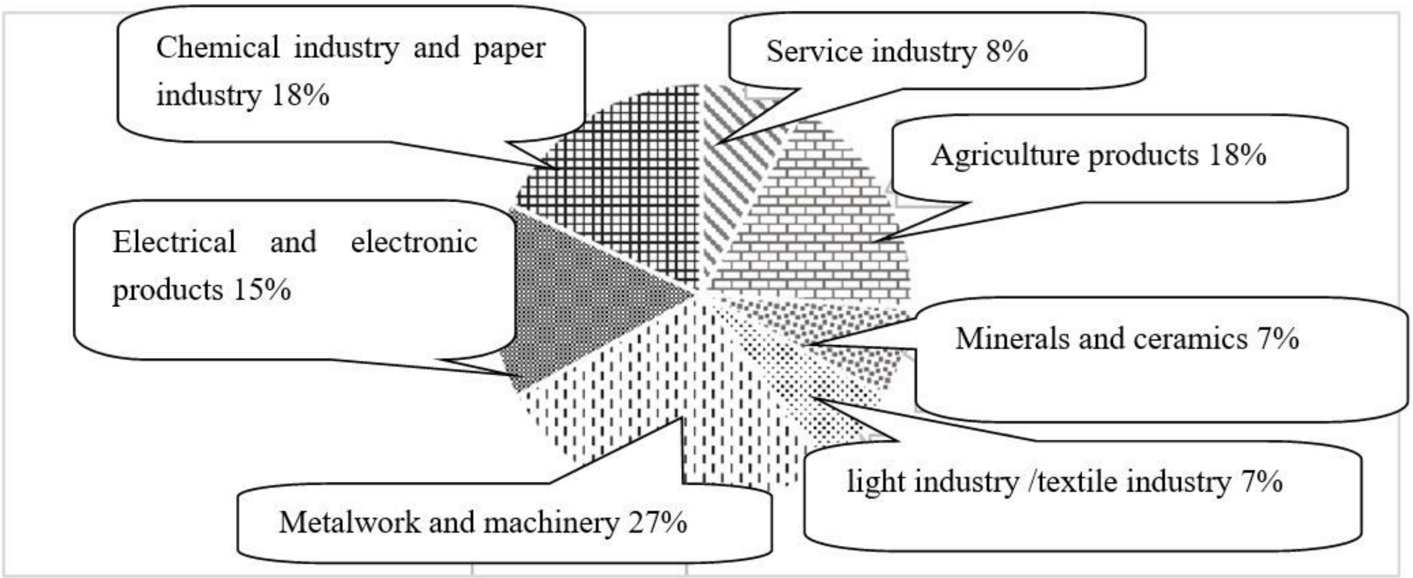

Figure 1

Industrial structure of China's investment projects in Thailand from 2012-2017 ,