The Inter-provincial Transfer of Transportation Hidden Carbon in China’s Provinces

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Abstract. Recognize the characteristics of the inter-provincial transportation hidden carbon transfer scientifically, which is significant to evaluate regional carbon emission correctly and reasonably and make the regional carbon reduction policies. With the China’s interregional input-output tables in 2007 and 2010 years, this paper measures the transportation hidden carbon and researches the features of inter-provincial transportation hidden carbon transfer. The results show that: (1) The Shanxi, Hubei and et al in central-western regions is the major importer of carbon emission, and the Tianjin, Jiangsu, Fujian and et al in eastern regions is the net exporter; (2) The transfer size and density of the eastern, central and western regions present the decreasing tendency. The more advanced the economy, the higher the transportation hidden carbon emission. In China, the Beijing-Tianjin-Hebei Economic Band is the most cohesive region about size and density. As the results, the responsibility of provincial transportation carbon emission should be properly adjusted, and regional linkage carbon emission policies should be implemented.

1. Introduction

Climate change has become a global environment challenges together. To reduce carbon emission and develop low-carbon economy have become the consensus of the international community. China is a large country which the level of economic development, industrial structure, and so on is obvious differences between different provinces. In the markets, there exists strong inter-provincial commodity trade and flows, reflecting that the local productions are used by other places. This causes the ‘carbon leakage’ [1]-[3]. Because the transportation is a service of providing spatial movement from one place to another. With the transfer of goods between provinces, the transportation also presents the characteristic of spatial transfer, thus transportation carbon also has this feature. Therefore, in order to measure regional transport carbon emission accurately, realize the responsibility of transport carbon and make the regional carbon emission policies, we need to cognize the condition of inter-provincial transportation carbon emission transfer.

At present, interregional correlation can influence the redistribution of carbon emission region, pollution transfer and so on obviously. And many scholars are interested in this respect. The researches about this most focus on: (1) the measurement, transfer and influences analysis of the interregional hidden carbon under the trade path[4]-[8]. (2) analysis of specific countries and regions carbon[8]-[13]. Some scholars research the hidden carbon transfer from industry perspective [14]-[16], and the papers of single industry focus on industry, electricity and heat production industry and so on. For the transportation carbon emission, the main research directions are the measurement and
evaluation about transportation carbon[17]-[19], spatial variance analysis[16],[20], influence factors analysis and so on[21]-[23]. Most of researches in transportation is analyzing based on the direct carbon emission, which is calculated by the data of energy consumption. However, this method ignores the hidden carbon emission, thus it can’t evaluate the regional carbon emission accurately. And few scholars research the inter-provincial transportation hidden carbon transfer in China.

Thus, based on the China’s interregional input-output tables, this paper analyses the condition of the inter-provincial hidden carbon transfer on transportation. We hope the results can become the references to adjust the responsibility of transport carbon reduction and make the carbon reduction policies.

2. Hidden carbon transfer calculations

Input-output table is the important part in national economic statistics, reflecting the economic transfers between different industries or different regions, so it can present the characterization of interregional transfer accurately. Therefore, based on the interregional input-output table in 2007 and 2010, this paper accounts transportation hidden carbon transfer.

In interregional input-output model, the relationship of supply and demand in different areas can be expressed as follows:

\[ X^e = A^{es}X^e + F^{es} + E^e \]  \hspace{1cm} (1)

In the formula: \( X^e \) is the output array in interregional input-output model; \( A^{es} \) is the input coefficient matrix; \( F^{es} \) is the final demand matrix; \( E^e \) is the exporting array.

Because the inter-provincial input-output model is the imported competition type in 2007 and 2010, and the input is not distinguished between imported products and domestic products. In order to account the provincial transportation hidden carbon emissions separately, we need to remove imported parts contained in input. This paper introduces imported excluding coefficient matrix to eliminate the part of import in the matrix. Imported excluding coefficients are evaluated as follows:

Intermediate demand imported excluding coefficient:

\[ \hat{M}_{ij}^e = \frac{M_{ij}^e}{\sum_{k=1}^{m} \sum_{l=1}^{n} X_{kl}^{es}} \]  \hspace{1cm} (2)

Final demand imported excluding coefficient:

\[ \hat{M}_{i}^f = \frac{M_{i}^f}{\sum_{k=1}^{m} \sum_{l=1}^{n} F_{kl}^{es}} \]  \hspace{1cm} (3)

After exclude, (1) can be rewritten as:

\[ X^e = \left( I - \hat{M}_{ij}^e \right) A^{es}X^e + \left( I - \hat{M}_{i}^f \right) F^{es} + E^e \]  \hspace{1cm} (4)

In the formula: \( \left( I - \hat{M}_{ij}^e \right) A^{es}X^e \) is intermediate demand excluding imports, \( \left( I - \hat{M}_{i}^f \right) F^{es} \) is the final demand supplied by domestic production.

Before calculating inter-provincial transportation hidden carbon transfer, we need to calculate the carbon emission coefficients first. Carbon emission coefficient means the carbon emissions under per unit of output, including direct carbon emission coefficient and complete carbon emission coefficient. The specific formulas are as follows:

\[ D^e = c^e / X^e \]  \hspace{1cm} (5)
\begin{align}
L_{rs}^{\text{vs}} &= D_{rs}^{\text{vs}} [I - (I - M_{x, r}^{s}) A_{rs}^{\text{vs}}]^{-1} \\
D_{rs}^{\text{vs}} &= \begin{bmatrix}
D_{r}^{s} & 0 & \cdots & 0 \\
0 & D_{r}^{s} & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & D_{r}^{s, o}
\end{bmatrix}
\end{align}
(6)

Among them, $D_{r}^{s}$ is direct carbon emission coefficient in R area, which is the proportion of direct carbon emissions $c_{r}^{s}$ with the transport sector gross products $x_{r}^{s}$; $L_{rs}^{\text{vs}}$ is the complete carbon emission coefficient between provinces. Interregional transport hidden carbon matrix $T_{rs}^{\text{vs}}$ is as follows:

\begin{align}
T_{rs}^{\text{vs}} &= L_{rs}^{\text{vs}} [I - M_{x, r}^{s}] E_{rs}^{\text{vs}}
\end{align}
(8)

3. Analysis of measured results

3.1 Analysis of transfer amount

According to the equation (5)-(7), this paper measures the inter-provincial transportation hidden carbon transfer matrix in 2007 and 2010. On this basis, transportation hidden carbon emission value of transfer-in, transfer-out and net transfer between provincial regions can be got in 2007 and 2010. The results about comparison of 2007 with 2010 show in the figure. 1, figure.2 and figure.3.

Figure 1. Comparison of provincial transportation hidden carbon transfer-in in 2007 and 2010.

Figure 2. Comparison of provincial transportation hidden carbon transfer-out in 2007 and 2010.
From those we can draw the following conclusions:

(1) The following provinces had larger transportation hidden carbon transfer-in amount: Shanghai, Hebei, Hubei, Inner Mongolia, Shanxi, Beijing and Guangdong. From 2007 to 2010 years, provincial transportation hidden carbon transfer-in amount were increasing, and Shanghai had the greater growth rate among these provinces. In addition, there were also individual provinces with a downward tendency, such as Beijing.

(2) The following provinces had larger transportation hidden carbon transfer-out amount: Tianjin, Jiangsu, Beijing, Fujian, Hebei, Inner Mongolia, Zhejiang. Viewing the trend as a whole, transportation hidden carbon transfer-out amounts in provinces were increasing. Beijing and Tianjin had more obvious growth among these provinces.

(3) According to the regional structure of transportation hidden net carbon transfer, there existed obvious regional imbalance. The provinces which had more transportation hidden net carbon transfer-in were mainly located in the central and western regions. The top three regions were Shanghai, Hubei and Shanxi in both 2002 and 2007, and the last three regions were Shanxi, Yunnan and Ningxia in 2007. And in 2010 the last three regions were Heilongjiang, Guangdong and Ningxia. However, the provinces which had more transportation hidden carbon net transfer-out were mainly located in coastal areas. The top three regions were Tianjin, Jiangsu and Fujian in 2007, and the last three regions were Hainan, Hebei and Hunan. In 2010 the last three regions were Hunan, Yunnan and Shandong.e use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

3.2 Transfer direction and structure analysis
By the visualization analysis tool——ARC GIS, figure.4 displays the inter-provincial transport carbon transfer matrix.

[Figure 4: For the convenience of visualization, the line is the connection with the center of mass, representing the inter-provincial transportation hidden carbon transfer in 2007 and 2010.]
It can be seen that transportation hidden carbon have both of the following characteristics in China:

1. Generally speaking, the carbon transfer size showed the following characteristics: eastern regions > central regions > western regions.

2. The transportation carbon transfer mainly occurred in the eastern-central regions, such as Beijing and Tianjin; Inner Mongolia and Tianjin; Shanghai and Beijing, Tianjin, Hebei, Inner Mongolia; Hubei and Tianjin; Shanxi and Tianjin. The size of transportation hidden carbon emissions in these provinces were more than 20 million tons, presenting the tendency of expansion.

For certain provinces, the transportation carbon emissions contain two parts, one is for developing their own economies and another one is for providing service to other provinces. From this perspective, this paper analyzes the composition of provincial transportation hidden carbon emissions in 2007 and 2010, shown in TABLE I.

As is shown in TABLE I, during 2007 and 2010, the percentage of carbon transfer-in is more than 25% in Beijing, Tianjin, Hebei and Shanxi, reflecting a quarter or more provincial transportation carbon emission is generated for improving the other provincial economics development.

However, the actual needs of transportation emissions for economic development are not only including the part generated for itself, but also including the portion transferred out to other provinces. Therefore, the actual transportation hidden carbon for provincial economic development is the sum of each column in the inter-provincial transportation carbon transfer matrix, as shown in figure 5.

Table 1. Provincial transportation hidden carbon emissions composition.

| Provinces       | Percentage of carbon transfer-in (%) | Provinces       | Percentage of carbon transfer-in (%) |
|-----------------|--------------------------------------|-----------------|--------------------------------------|
|                 | 2007       | 2010       |                                       | 2007       | 2010       |
| Beijing         | 30.9       | 19.2       | Henan                                | 3.2        | 2.4        |
| Tianjin         | 27.5       | 26.3       | Hubei                                | 18.2       | 19.9       |
| Hebei           | 27.8       | 32.4       | Hunan                                | 2.6        | 2.5        |
| Shanxi          | 9.4        | 9.3        | Guangdong                            | 4.4        | 5.9        |
| Inner Mongolia  | 25.9       | 18.3       | Guangxi                              | 15.7       | 14.8       |
| Liaoning        | 2.4        | 2.0        | Hainan                               | 4.5        | 24.0       |
| Jilin           | 22.2       | 21.2       | Chongqing                            | 12.2       | 16.1       |
| Heilongjiang    | 8.1        | 7.7        | Sichuan                              | 2.2        | 2.8        |
| Shanghai        | 21.0       | 29.8       | Guizhou                              | 13.2       | 12.2       |
| Jiangsu         | 2.6        | 2.7        | Yunnan                               | 11.3       | 6.0        |
| Zhejiang        | 10.0       | 11.1       | Shaanxi                              | 33.8       | 26.4       |
| Anhui           | 23.2       | 29.7       | Gansu                                | 0.0        | 0.0        |
| Fujian          | 4.2        | 5.7        | Qinghai                              | 0.2        | 0.4        |
| Jiangxi         | 1.8        | 1.9        | Ningxia                              | 12.6       | 12.1       |
| Shandong        | 0.9        | 0.9        | Xinjiang                             | 20.6       | 20.8       |

Figure 5. Provincial actual transportation hidden carbon emission in 2007 and 2010
From the regional distribution, economically developed provinces had high transportation hidden carbon emissions, like Shandong, Guangdong, Liaoning, Jiangsu and Shanghai. On the contrary, western areas were less, like Gansu, Qinghai and Ningxia. This suggests that: the more advanced the economy and the more frequently the foreign economic ties, the higher the transportation hidden carbon.

From the changing trends, the level of provincial transportation hidden carbon emission were overall on the rise during 2007 to 2010. However Shandong had been slipping, implying that the Shangdong’s polices of economic structural adjustment and transportation carbon reduction had made effects.

4. Conclusions and recommendations
Based on the interregional input-output tables between China’s provinces in 2007 and 2010, this paper studies the transportation hidden carbon transfer between the 30 provinces.

(1) The provinces which transportation hidden carbon transfer-in is large contained Shanghai, Hebei and Hubei. Tianjin, Jiangsu, Beijing, and other provinces had large carbon transfer-out. Among them, the provinces of net transfer-in mainly concentrated in the central-western region, such as Hubei and Shaanxi. The provinces of net transfer-out mainly concentrated in eastern coastal areas, like Tianjin, Jiangsu and Fujian.

(2) The scale of transportation carbon showed the characteristics: the eastern regions > central region > western regions. The transportation hidden carbon transfer occurred mainly in Beijing and Tianjin region, Shanghai and Beijing, Tianjin, Hebei, Inner Mongolia region, and the size of the transfer had a tendency to expand.

(3) From the structure of transportation carbon emission, 1/4 or more transportation carbon of some provinces is generated for others, such as Beijing, Tianjin, Hebei, and Shaanxi.

(4) In terms of the actual traffic hidden carbon emissions caused by economic development in provinces, Shandong, Guangdong, Liaoning, Jiangsu and other economically developed provinces’ traffic hidden carbon was higher, while Gansu, Qinghai, Ningxia and other western backward areas had the low carbon traffic carbon.

Therefore, when we are designing the traffic carbon emission reduction policy in the future, we should reduce the responsibility of large transfer-in provinces appropriately, like Shanghai, Hebei, Hubei and Shaanxi, and increase responsibility of the transfer-out provinces, such as Tianjin, Jiangsu, Shandong, Guangdong and Liaoning. At the same time, for the provinces which are connected with large transfer scale, they should make the joint carbon reduction policy from the the industrial structure adjustment, such as Beijing and Tianjin, Shanghai and Beijing, Tianjin, Hebei and Inner Mongolian.

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