Carbon association studies of whole industrial chain

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Abstract. With the coordinated development at "Beijing-Tianjin-Hebei", industrial transfer is bound to bring carbon transfer. Industrial transfer along inter-regional industrial chain has become one of the main forms of industry transfer. So the problems of carbon transfer that happened between industry chain and regional must be pay more attention. This paper based on inter-regional input-output model, counted input-output tables of 2014 on the base of the input-output tables of 2010 to analysis the problems of carbon transfer between upstream and downstream in "Beijing-Tianjin-Hebei" from 2010 to 2014. This paper studied inter-regional, intra-regional, inter-industry, intra-industry carbon linkage in “Beijing-Tianjin-Hebei”, in order to provide help for inter-industry cooperative carbon emissions reduction in "Beijing-Tianjin-Hebei”

1. Introduction
Carbon emissions in Beijing-Tianjin-Hebei region accounted for about 20% of the national carbon emissions. Ecological environment problems which were created by high pollutants emission have become an important bottleneck restricting the sustainable development of Beijing-Tianjin-Hebei. Realizing the coordinated development between Beijing, Tianjin and Hebei, carbon transfer problems should be pay more attention.

Economic development in "Beijing-Tianjin-Hebei” is unbalanced, which created inter-regional industrial gradient transfer. Industrial transfer will lead to the spatial transfer of carbon emission (Xu 2010, Chen 2006, Dou 2014, Kheder 2012, Liu 2014), which had done a lot of research by domestic and foreign scholars. Peters believed that international trade made the carbon emissions transfer freely, and producers and consumers of products should bear the responsibility for carbon emissions (Peters 2008). Wang et al estimated commercial carbon emissions. He argued that developing countries as a producer undertook a large number of CO₂ for developed countries (Wang 2011). For the emission problem caused by domestic industrial transfer, Cheng, Wei argued that industry transfer increased carbon emission of transferred area (Cheng 2013).

These views focused on inter-regional carbon transfer generated from the trade and circulation. In addition to, there were also problems of carbon transfer between upstream and downstream. Upstream provides products and services for downstream. This relation made upstream industry undertake a lot of carbon emissions for the downstream industry. That inter-regional industry transfer along the industry chain has become the main form. Therefore, the carbon transfer in this paper refers to the transfer between the upstream and downstream. Definitions are as follows. Industry A invested carbon in industry B. Carbon emission transferred from industry A to industry B. In order to clarify the direction of industrial carbon transfer, this paper studied carbon transfer problem between upstream and...
downstream based on the multi-regional input-output table. It aimed at adjusting the industrial structure from the perspective of the whole industry chain, to promote synergic development of Beijing-Tianjin-Hebei from industry.

2. Mythology and Date sources

2.1. Estimating carbon emission intensity

This paper used the method which was provided by the United Nations Intergovernmental Panel on climate change (IPCC) to estimate the total CO$_2$ emissions. We calculated carbon emission intensity as follows:

$$ S_j = \frac{\sum_{i=1}^{k} C_{ii} N_j x c_i}{E_j} = \frac{\sum_{i=1}^{k} N_j x c_i}{E_j} $$

(1)

Where $S$ is carbon emission intensity; $E$ is total output, in terms of GDP; $j$ is the jth industry; $i$ is the ith type of energy, which includes coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel oil and natural gas; $N$ is energy consumption; $c$ is emission coefficient of energy, as shown in Table 1.

| Energy type          | coal  | coke  | crude oil | fuel oil | gasoline | kerosene | diesel oil | natural gas |
|----------------------|-------|-------|-----------|----------|----------|----------|------------|-------------|
| $c_i (t / t)$        | 0.7759| 0.8550| 0.5857    | 0.6185   | 0.8150   | 0.5714   | 0.5921     | 0.4483      |

2.2. Multi-regional input-output model

Multi-regional input-output table can reflect the economic relations between different industries, different regions and different industries. According to the multi-regional input-output table, the increment of intermediate inputs between industries under $t_1$-$t_2$ can be expressed as:

$$ \Delta x_{ij}^{rh} = x_{ij(t_2)}^{rh} - x_{ij(t_1)}^{rh} $$

(2)

Where $i$ and $j$ is the type of industry; $r$ and $h$ is the type of region; $x_{ij}^{rh}$ is industry $i$ of region $r$ invest in industry $j$ of region $h$; $\Delta x_{ij}^{rh}$ is the increment that industry $i$ of region $r$ invest in industry $j$ of region $h$. Assuming that the carbon emission coefficient is constant, the increment that Industry $i$ of region $r$ invest carbon in industry $j$ of region $h$ is:

$$ \Delta C_{ij}^{rh} = \Delta x_{ij}^{rh} S_i' $$

(3)

Where $S$ is carbon emission intensity? Therefore, the total carbon input that region invest in other regions during the period of $t_1$-$t_2$ increased:

$$ \Delta C' = \sum_{h=1}^{m} \sum_{i=1}^{n} \sum_{j=1}^{n} \Delta C_{ij}^{rh} $$

(4)

The increment that other regions invest carbon in region $r$ during $t_1$-$t_2$ is:
\[ \Delta C^r = \sum_{h=1}^{m} \sum_{t=1}^{n} \sum_{j=1}^{n} \Delta C^r_{ji} \quad (5) \]

2.3. Date source
The regional input-output table (2010) was derived from Inter-regional Input-output Table of 30 Provinces, China (2010) (Liu 2011). Assuming that trade relations between industries are invariant, regional input-output table of 2014 was calculated based on regional input-output table of 2010. The date regarding industry energy consumption was derived from the Chain Energy Statistical Yearbook. According to Inter-regional Input-output Table of 30 Provinces, China (2010), industry was divided into six sectors: agriculture, industry, Construction Industry, transportation and storage industry, wholesale and retail industry, other services industry. A, I, C, TS, WR, OS, B, T, H are the abbreviations of agriculture, industry, Construction Industry, transportation and storage industry, wholesale and retail industry, other services industry, Beijing, Tianjin, Hebei.

3. Analysis of industrial carbon correlations

3.1. Carbon emission intensity for industry
According to the formula (1), this paper accounted carbon emission coefficient for each industry in "Beijing-Tianjin-Hebei", as shown in figure 1. Carbon emission intensity was largest in Hebei province. And it was least in Beijing. The carbon emission intensity of industrial was biggest among the six sectors. And the industry in Hebei had the largest carbon emission intensity in all sectors.

![Figure 1 Carbon emission intensity for each industry](image)

3.2. Inter-industrial carbon linkage in “Beijing-Tianjin-Hebei”
According to the formula (4) - (5), this paper accounted the changes of carbon input and carbon use in "Beijing-Tianjin-Hebei", as shown in Table 2. Figure 2-4 showed that the change of intrt-industrial carbon input in "Beijing-Tianjin-Hebei", the arrow indicated the direction of carbon input, the width of arrow represented the increased proportion of carbon inputs. For example, increased proportion that industry of Beijing invested carbon in industry of Tianjin is divide the increment of industry of Beijing invested carbon in Tianjin.

|               | increment of carbon use | increment of carbon input |
|---------------|-------------------------|---------------------------|
| Beijing       | 50.58                   | 9.94                      |
| Tianjin       | 578.92                  | 582.95                    |
| Hebei         | 584.59                  | 621.20                    |

The increment of carbon use was greater than the increment of input in Beijing from 2010 to 2014. It was the opposite in Tianjin and Hebei. Carbon use of Beijing increased 50.58 million tons from 2010.
to 2014. And 48% of these came from increment that Hebei invested in Beijing. Increment of carbon use in Tianjin or Hebei was 10 times more than the increment in Beijing.

3.2.1. Inter-industrial carbon linkage in Beijing. Input that Beijing invested carbon in itself increased by 97.89 million tons. And the increment of carbon input for other services industry was obvious (the proportion is 55%) from 2010 to 2014. For other services industry, 36% of the input increment came from itself, 12% of the input increment came from industry. There was carbon input correlation between industry and other services industry. The carbon input obviously increased during 2010 to 2014. In addition, wholesale and retail industry invested more carbon in industry. For industry, the final result showed that the increase of carbon use was greater than the increase of carbon input.

The increment of input that Tianjin invested carbon in Beijing mainly focused that industry, Construction Industry of Tianjin invested in industry of Beijing, wholesale and retail industry of Tianjin invested in other services industry of Beijing, transportation and storage industry of Tianjin invested in transportation and storage industry of Beijing. The increased input that Hebei invested carbon in Beijing had a lot of transfer path. And increased input that industry, wholesale and retail industry of Hebei invested in industry of Beijing, transportation and storage industry, wholesale and retail industry of Hebei invested in other services industry of Beijing had higher proportion.

![Figure 2](image_url)

**Figure 2** Main transfer paths of carbon transfer in Beijing area from 2010 to 2014.

3.2.2. Inter-industrial carbon linkage in Tianjin. Increment of carbon use in Tianjin region inside mainly because that carbon use of industry increased (industry made up about 61% of the increment). Input that transportation and storage industry, wholesale and retail industry invested carbon in industry obviously increased. The proportion was 19%, 21%. Therefore, Tianjin should strengthen cooperation between wholesale and retail industry and industry, transportation and storage industry and industry to curb the increase of carbon transfer. Carbon use of Construction Industry increased small. The proportion was 8%. While Carbon input of Construction Industry also increased small. Construction Industry had become the sector that the increment of carbon use was more than increment of carbon input.

Input that Beijing invested carbon in Tianjin slightly increased from 2010 to 2014. But the Contribution was negligible. That Hebei invested carbon in Tianjin increased. We can see that the increment mainly embodied that agriculture, industry, transportation and storage industry of Hebei invested in industry of Tianjin, transportation and storage industry of Hebei invested in transportation and storage industry of Tianjin. The proportion was 10%, 11%, 36%, 10%.
3.2.3. *Inter-industrial carbon linkage in Hebei.* From 2010 to 2014, carbon input which Hebei invested itself region significantly increased. 63% of the increment was that other services industry invested carbon in industry. That carbon use of industry increased mainly due to industry, agriculture, transportation and storage industry, wholesale and retail industry invested more carbon in industry. From 2010 to 2014, carbon input which Beijing invested in Hebei increased by 0.8256 million tons. Increased input that industry and other services industry of Beijing invested in Hebei was in the majority. Carbon input that Tianjin invested in Hebei increased. These mainly were due to the increase that industry, transportation and storage industry of Tianjin invested in industry of Hebei. And the proportion was 30%, 21%.

4. Conclusion
In Beijing, the increment of carbon use was 50.58 million tons, while the increment of carbon input was 9.94 million tons from 2010 to 2014. That indicated that Tianjin and Hebei undertook more carbon emissions for Beijing in 2014. The increase of carbon transfer in Beijing was mainly due to the increase input that Hebei invested in Beijing. Therefore, from the perspective of ecological compensation, Beijing should provide a number of compensation for Tianjin and Hebei. For specific industry, the carbon input increased markedly industry. For example, carbon input among industry increased 86.40 million tons in Tianjin from 2010 to 2014. Therefore, we should continue to adjust the internal structure of the industry, to toward the direction of low energy consumption and low emission. Because of the existence of carbon transfer between industries, different industries need to assume jointly responsibility for emission reduction. We should determine the appropriate ratio of reduction emission between upstream and downstream through the attribution of responsibility, emission reduction capacity and emission reduction responsibility.
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