Provincial carbon footprint and interprovincial carbon emissions transfer ——An provincial input-output analysis

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Abstract: Carbon footprint is to measure the direct and indirect total carbon emissions by different individuals or organizations in order to meet their needs, the research of provincial carbon footprint and interprovincial transfer of carbon emissions has important practical significance to regional targets of carbon emission reduction. Based on the data of provincial input-output model and the carbon footprint model, the analysis is focused on provincial carbon footprint and the space transfer of carbon emissions. The results have shown that: (1) There are significant differences of provincial total carbon footprint amounts: resource-rich provinces have high total carbon footprint amounts, followed by processing and manufacturing provinces and municipalities; Regions with high energy efficiency have low carbon footprint amounts, so does southwestern region where economic and industrial development level is relatively low. (2) The provincial differences of carbon footprint per capita are related to demand structure: the amounts of carbon footprint are high in provinces with higher demand of consumption and investment, especially those provinces with strong demand for construction and processing industries. The amounts of carbon footprint are low in provinces which are non-resource-based, have limited investment and construction, and its economic structure is not dominated by processing and manufacturing. (3) Provincial carbon emission per capita is closely related to carbon footprint per capita: in provinces where carbon emission per capita is lower than carbon footprint, the ratios of consumption and investment are high, or service industries make up a significant portion in provincial economies. In provinces where carbon emission per capita is higher than carbon footprint per capita, economies are developed, and energy-intensive industries make up a large portion in provincial economies. (4) Interprovincial trades have a significant impact on carbon footprint and carbon emissions. Provinces with well developed infrastructure have net CO_2 emissions transfer-in that are directly induced by high energy consumption products; southwestern region, where processing and manufacturing industry is relatively less-developed, has main CO_2 emission transfer-in, which are induced by the demand of processing and manufacturing industries; resource-intensive provinces and provinces with well-developed processing and manufacturing industries have net CO_2 emission transfer-out, which are induced by interprovincial trades. (5) The interprovincial transfer of carbon emissions are closely related to interprovincial trades. However, the differences of resource structure, industrial structure and development level result in the regional differences of provincial transfers of CO_2 emissions. The trends of CO_2 emission transfer in most provinces are the same as those of trade inflow and outflow, while in a small number of provinces, the trends are in the opposite direction of trade inflow and outflow.

Key words: carbon footprint,input-output, carbon emissions transfer

1. Induction

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Carbon Footprint is a concept that measures the carbon emission levels, based on the concept of ecological footprint. For now, there is no uniform definition of Carbon Footprint, scholars differ in the understanding and awareness of it. British Petroleum believes that Carbon Footprint refers to the total CO2 emissions from our daily activities[1]. Grub & Ellis believe that Carbon Footprint is the total amount of CO2 released from the consumption of fossil fuels[2]. Wang Wei has reviewed and sorted out 11 types of carbon footprint definitions. Based on Wiedmann & Minx, Wang Wei thinks that Carbon Footprint is the total amount of CO2 emissions by particular product or service system in it full life cycle, or, Carbon Footprint is the total amount of direct and indirect CO2 emissions by activity principals (including individuals, organizations, sectors, etc.) [3], presented in the form of CO2 equivalent, i.e., total amount of direct and indirect CO2 emissions which meets the needs of principals' daily life. Thus, the concept of Carbon Footprint is limited by some scholars within the direct emission from the consumption of fossil fuels, while some other scholars believe that it should also include the indirect carbon emissions from the consumption of consumer products.

So far, the research of carbon footprint has included four levels of analysis: individual, product, enterprise, and region (country/city). Product carbon footprint refers to the amount of greenhouse gas emissions from a single product manufacture, usage, and disposal stages, "from cradle to grave", from the use of fuel, manufacture and transportation. Enterprise carbon footprint includes not only product carbon footprint, but also carbon emission from non-manufacturing activities. Regional carbon footprint focuses on the carbon emission amount from the overall material and energy consumption in a country or city, direct and indirect, import and export.

There are two kinds of carbon footprint methods: Top-Down and Bottom-Up. The former is based on the life-cycle method and input-output model, to measure the total carbon emission amount induced by end-user demand; it is the main method to analyze carbon footprint in the family and regional levels. Based on the estimates of actual daily consumption and transportation pattern and the use of carbon footprint calculator, the latter is to obtain the input and output data list of the research target through the life-cycle checklist analysis, and in turn obtain the carbon emission info. Such method is mainly applied in the analysis of product carbon footprint and enterprise carbon footprint.

As the climate change has become a global issue that can't be ignored, the analysis of carbon footprint has been a national and international concern, especially the associated studies of international trade and carbon footprint[32]-[35]. Christopher and Weber have used the inter-regional input-output model and the life-cycle assessment approach[11], with the expenditure research, analyzed the impact on the carbon footprint of U.S. households by international trades. With the rise of the concept of low-carbon economy, many scholars have switched to the research of family carbon footprint. With the application of multi-regional input-output model, Druckman and Jackson have analyzed the family carbon footprint in different countries on a time scale[22]. And Padget has applied 10 kinds of carbon footprint models, to calculate the family carbon footprint in USA[23]. So far, there hasn't been much regional scale analysis of carbon footprint; the research of space transfer of carbon emission which includes interprovincial economic ties, has been rare.

Carbon footprint analysis can help to grasp the awareness and activities by individuals and organizations and its impact on global environment; it can also provide scientific reference for the decomposition of responsibilities of carbon emission reduction. There have been significant regional differences in China; due to the differences of resource pattern, industrial structure and economy development level, there have been big differences of carbon footprint in various provinces. Especially with the marketing and regional integration, the interprovincial economic connection has become stronger. Due to the space transfer of carbon emission caused by the interprovincial trade of services and goods, there has been discrepancy between carbon footprint and actual carbon emission. Therefore, not only actual carbon emission, but also the impact by the space transfer of carbon emission, should be included in the consideration of provincial emission reduction responsibilities. Caoshuyan and others have calculated the direct carbon emission amount by fossil fuel consumption in various provinces[32], but haven't considered the space transfer of carbon emission, which is hidden in interprovincial trade of services and goods. Based on the interprovincial input-output model thus the carbon footprint model, this article will quantify and analyze the carbon footprint in various provinces and the interprovincial space transfer of carbon emission, in-depth study the impact of interregional and international trade on the carbon footprint of each province, in order to provide a scientific basis of reference and quantification, for the regional decomposition of responsibility of carbon emission reduction.

2. Methods

2.1 Carbon footprint model

The analysis of carbon emissions based on provincial input-output model. Compared with the national input-output table, provincial input-output table added the columns of "inflow" and "outflow"in the final use, this helps to clearly demonstrated the economic interprovincial economic contacts.

The standard regional input-output model is represented by Eq.1

$$x_i^R = \sum_{j=1}^{n} x_{ij}^R + \sum_{k=1}^{m} y_{ik}^R \qquad (1)$$

Where x_i^R represents the total output of sector i in region R; x_{ij}^R represents the intermediate consumption of sector j supplied by sector i in region R. y_{ik}^R represents the k kinds final consumption(consumption, investment etc.) of region R supplied by sector i. R=1,2,⋯,30; i,j=1,2, ⋯,60;k=1,2, ⋯,10.

The direct input coefficient a_{ij}^R indicates the amount of input from sector i required to increase one monetary unit output of sector j in region R. a_{ij}^R can be obtained by dividing the sectoral flow x_{ij}^R with total output x_j^R:

$$a_{ij}^R = x_{ij}^R / x_j^R \qquad (2)$$

Therefore, Eq.1 can be rewritten as:

$$x_i^R = \sum_{j=1}^{n} a_{ij}^R x_j^R + \sum_{k=1}^{m} y_{ik}^R \qquad (3)$$

Eq.3 can be shown as follows in matrix notation:

$$X^* = A^* X^* + Y^* \qquad (4)$$

Where X^*, A^* and Y^* are respectively the matrixes of output, direct input coefficients and final consumption.

Assuming the matrix A^* of direct input coefficients is constant, it is possible to change Eq.4 into a consumption-driven format:

$$X^* = (I - A^*)^{-1} Y^* \quad (5)$$

Where $(I-A^*)^{-1}$ is know as Leontief inverse matrix which shows how much output each sector in each region is required to meet one monetary unit of the final consumption.

The above equations calculate how much the changes in final consumption determine the sectoral output in monetary term. In order to link the monetary output with CO2 emissions, the essential step is to derive the direct CO2 emissions coefficient, which is defined as the amount of direct CO2 emissions to produce one monetary unit of output. It represents the direct CO2 emissions intensity of a sector. The direct CO2 emissions coefficient can be expressed as Eq.6.

$$E^R = (e_j^R), e_j^R = c_j^R / x_j^R \quad (6)$$

Where E^R is the matrix of direct CO2 emissions coefficients (measured in kgCO2/10^4yuan in this study); e_j^R is the CO2 emissions coefficient of sector *j* in region *R*; c_j^R is the total amount of CO2 emissions of the sector *j* in region *R* and x_j^R is the output (in monetary term) of sector *j* in region *R*

The regional carbon footprint can be derived by incorporating the carbon emissions in the regional input-output calculation as shown in Eq.7.

$$C^R = E^R \left[(I - A^*)^{-1} Y^{RU} \right] = (E^R (I - A^*)^{-1}) Y^{RU} \quad (7)$$

Where C^R is the CO2 emissions in region *R* which indicates the total amount of CO2 emissions used in meeting the final consumption of the inhabitants in region *R*.

2.2 The method of interprovincial carbon emissions transfe

The amount of outflow carbon emissions from region R calculation as shown in Eq.8.

$$C^{RO} = E^R \left[(I - A^*)^{-1} Y^{DR} \right] = (E^R (I - A^*)^{-1}) Y^{RO} \quad (8)$$

Where C^{RO} is the matrix of outflow carbon emissions induced by goods and serves flow from region R; Y^{RO} is the matrix of outflow in final consumption in region *R*.

The amount of inflow carbon emissions in region R calculation as shown in Eq.9.

$$C^{RI} = E^R \left[(I - A^*)^{-1} Y^{RI} \right] = (E^R (I - A^*)^{-1}) Y^{RI} \quad (9)$$

Where C^{RI} is the matrix of inflow carbon emissions induced by goods and serves flow to the region R; Y^{RI} is the matrix of inflow in final consumption in region *R*.

The amount of carbon emissions transfer calculation as shown in Eq.10.

$$C^{RZY} \quad \sum_{i=1}^{60} c_i^{RI} - \sum_{i=1}^{60} c_i^{RO}$$

Where C^{RZY} is the amount of carbon emissions transfer.

(Note: The inflow goods and serves from which provinces can not obtained exactly,so the same carbon emissions coefficient was used for those inflow and outflow goods and serves)

2.3 Date

Primary energy are all taken from China Energy Statistical Yearbook (2003); 60 sector input-output tables of 30 provinces in 2002, the emissions factors are from the report of IPCC.

To avoid double calculation, in this paper fossil energy such as coal, petroleum and natural gas are considered and included, hydropower, nuclear power and renewable energy are neglected.

3.The result

3.1 Comparison of regional carbon footprint

There are significant differences of the total amount of carbon footprint among the 30 provinces. The amount of carbon footprint in Shandong province is 16times more than that of Qinghai province. Carbon footprint from high to low were classified into 4 categories: Shandong，Hebei,Jiangsu,Shanxi,Guangdong and Jilin are category 1 which hold an abundance of mineral resources; Category 2 are provinces which advanced manufacturing such as Liaoning, Shanghai,Hubei,Henan,Beijing,Zhejiang, Heilongjiang,Sichuan, Anhui, Neimenggu,Shan'xi, Chongqing. Category 2 areYunnan,Xinjiang,Gansu,Guangxi,Hainan and Qinghai provinces with the backwardness of the economy(Fig.1).

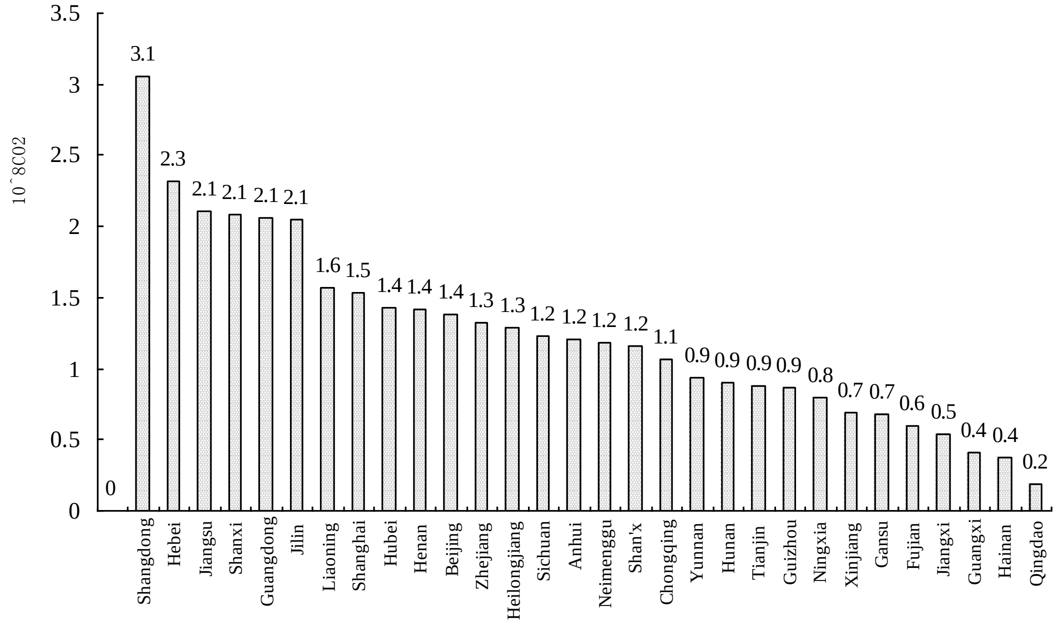

Fig .1 The amount of carbon footprint of 30 provinces in China 2002

Per capita carbon footprint can be divided into three categories, In terms of per capita carbon footprint level,Ningxia, Beijing,shanghai,Jilin,Shanxi,Neimenggu,Hainan,Tianjin are at the highest level(per capita carbon footprint is better than 4 tonCO2):Liaoning,Xinjiang,Qinghai, Hebei,Chongqing,Heilongjiang,Shandong,Shan’xi,Jiangsu,Zhejiang,Guangdong,Gansu,Hubei,Guizhou and Yunnan are at moderate level(per capita carbon footprint is better than 2 tonCO2 and less than 4 tonCO2);Anhui,Fujian,Henan,Sichuan,Hunan,Jiangxi and Guangxi are at the lowest level(per capita carbon footprint is less than 1 tonCO2)(Fig. 2)

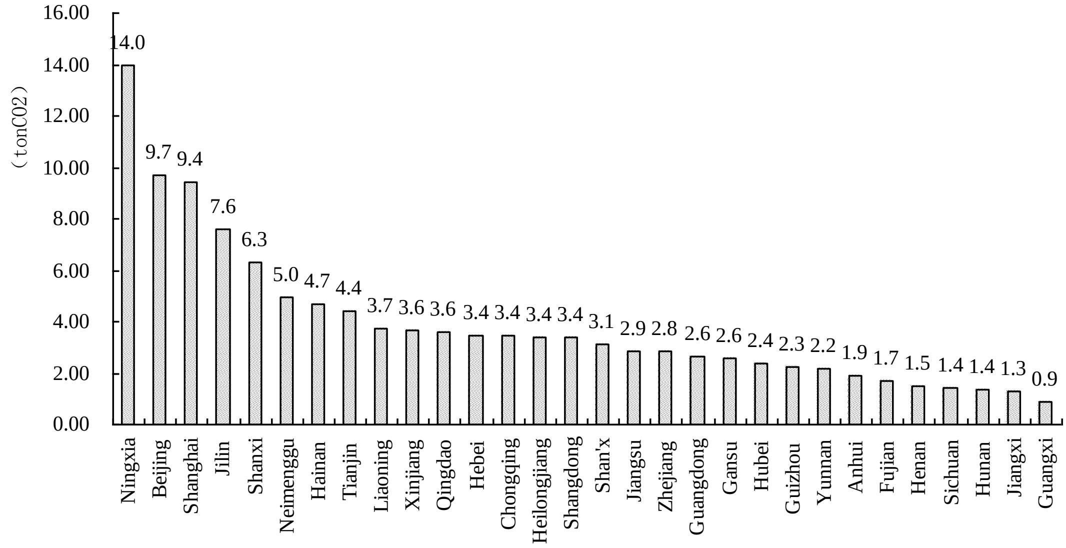

Fig.2 Per capita carbon footprint of 30 provinces in China 2002

The regional difference of per capita carbon footprint relate to the final demand structure. There are larger carbon footprint in those provinces which are high consumption and high investment, especially in construction and manufacturing accelerated provinces. Those resource-scarce, building-backward provinces have lower carbon footprint. The per capita carbon footprint of Ning xia is largest. Two points of view for further understanding: Firstly, small in population, Ningxia owned 0.08 billion tons carbon footprint while 5.72 million populations. Secondly, the relative low efficiency of energy, In NingXia, CO2 emissions to produce one monetary unit of output is higher than that ofother provinces. the larger per capita carbon footprint of Beijing and Shanghai is for two reasons, first reason, the two cities are all developed areas, high wages and high consumption; second reason, the construction of the infrastructure are developed in the cities, 52% the carbon footprint induced by the construction of the infrastructure.

Guangxi and Jiangxi are the areas with fewer resources, undeveloped manufacturing and limited construction of the infrastructure, so the total amount and per capita carbon footprint of are fewer(the amount of carbon footprint, 0.053 billion tons CO2 in Guangxi, 0.041 billion tons CO2 in Jaingxi (Table.1).

Table 1 Carbon footprint construction induced final consumption（Unit：10^^{8} ton CO2）

Region	Rural	Urban	Government	Capital	Stock	CFP	Rural	Urban	Government	Capital	Stock	CFP
Beijing	0.06	0.42	0.21	0.65	0.05	1.3	5%	30	15	47%	4%	100%
tianjin	0.06	0.29	0.11	0.36	0.06	0.8	7%	33	12	41%	7%	100%
Hebei	0.44	0.39	0.20	1.05	0.25	2.3	19	17	8%	45%	11%	100%
Shanxi	0.25	0.53	0.28	1.06	-0.0	2.0	12	25	13	51%	-1%	100%

Neimenggu	0.12	0.35	0.10	0.57	0.04	1.1	10	30	8%	48%	3%	100%
Liaoning	0.15	0.53	0.19	0.62	0.09	1.5	9%	34	12	39%	6%	100%
Jilin	0.53	0.24	0.13	1.13	0.02	2.0	26	12	6%	55%	1%	100%
Heilongjiang	0.13	0.48	0.17	0.46	0.05	1.2	10	37	13	36%	4%	100%
Shanghai	0.07	0.53	0.11	0.79	0.02	1.5	5%	35	7%	52%	1%	100%
Jiangsu	0.31	0.44	0.24	0.96	0.16	2.1	15	21	11	46%	8%	100%
Zhejiang	0.27	0.23	0.16	0.63	0.04	1.3	20	17	12	48%	3%	100%
Anhui	0.25	0.26	0.08	0.59	0.04	1.2	20	21	7%	48%	3%	100%
Fujian	0.16	0.09	0.07	0.16	0.11	0.5	26	15	12	28%	19%	100%
Jiangxi	0.10	0.11	0.05	0.26	0.02	0.5	19	21	9%	49%	3%	100%
Shandong	0.56	0.45	0.20	1.57	0.28	3.0	18	15	7%	51%	9%	100%
Henan	0.24	0.30	0.15	0.55	0.17	1.4	17	21	11	39%	12%	100%
Hubei	0.39	0.23	0.10	0.61	0.10	1.4	27	16	7%	43%	7%	100%
Hunan	0.18	0.18	0.09	0.43	0.02	0.9	20	20	10	48%	3%	100%
Guangdong	0.58	0.25	0.33	0.85	0.05	2.0	28	12	16	41%	2%	100%
Guangxi	0.10	0.13	0.07	0.20	-0.0	0.4	25	31	17	49%	-21%	100%
Hainan	0.07	0.08	0.03	0.19	0.02	0.3	18	20	8%	49%	5%	100%
Chongqing	0.17	0.27	0.10	0.50	0.03	1.0	16	25	10	47%	3%	100%
Sichuan	0.24	0.21	0.12	0.61	0.04	1.2	19	17	10	50%	4%	100%
Guizhou	0.16	0.13	0.11	0.48	-0.0	0.8	19	15	12	55%	-1%	100%
Yunnan	0.21	0.14	0.15	0.47	-0.0	0.9	22	14	16	50%	-3%	100%
Shan’xi	0.15	0.23	0.06	0.68	0.04	1.1	13	20	5%	59%	3%	100%
Gansu	0.10	0.17	0.08	0.31	0.01	0.6	14	26	12	46%	2%	100%
Qinghai	0.02	0.05	0.02	0.10	0.00	0.1	11	24	12	54%	-1%	100%
Ningxia	0.07	0.13	0.08	0.49	0.03	0.8	9%	17	10	61%	4%	100%
Xinjiang	0.07	0.16	0.09	0.36	0.02	0.6	10	23	13	52%	2%	100%

3.2 The relationship of per capita carbon footprint and per capita carbon emissions

The total amount of carbon emissions in different provinces from high to low were classified into 3 categories：Hebei,Shandong,Jiangsu,Guangdong,Shandong,Liaoning,Henan,Zhejiang, Hubei,Shanghai are at the highest level, These provinces are economically developed and energy-intensive businesses areas. Xinjiang,Ningxia,Gansu,Guangxi,Qinghai and Hainan are at the lower level, there are fewer resources, undeveloped manufacturing in these areas. The difference of per capita CO2 emissions relate to population, economic level, resources distribution, industrial structure in 30 provinces.

There are a good correlation between per capita CO2 emissions and per capita CO2 footprint(the correlation coefficient is 0.89),Some provinces such as Beijing,Ningxia,Jilin,Hainan, Shanghai,Chongqing,Tianjing,Shandong,Xinjiang,Yunnan,Gansu,Guizhou,Heilongjiang,Anhui,Sichuan, per capita CO2 emissions is lower than per capita CO2 footprint. Other provinces including Liaoning,Hebei,Zhejiang,Guangxi,Henan,Fujian Neimenggu, per capita CO2 emissions is higher than per capita CO2 footprint(Fig.3)

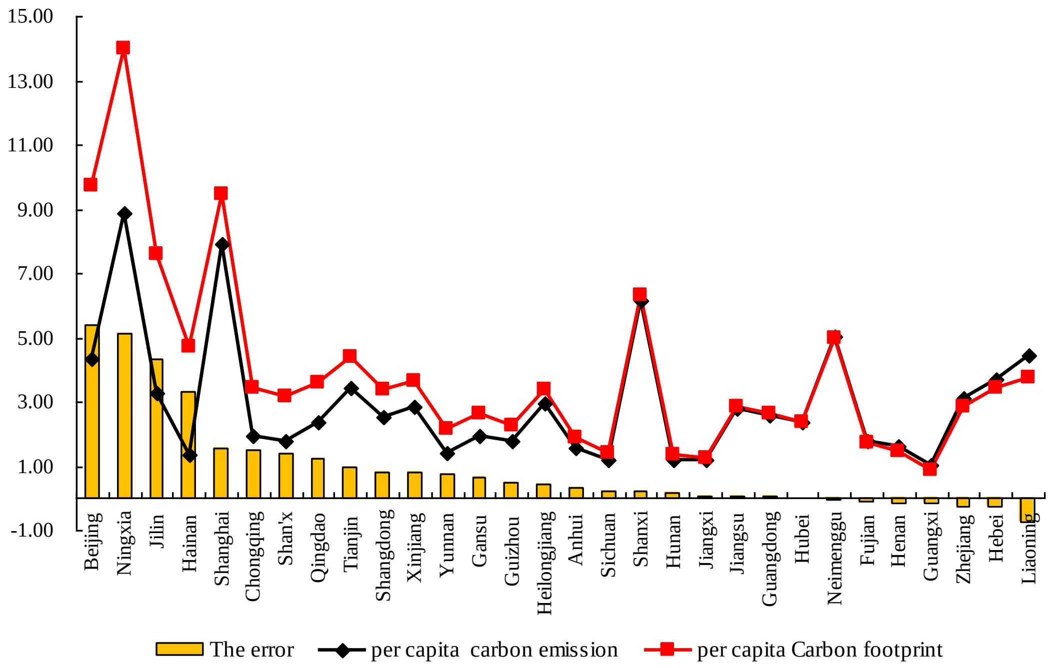

Fig. 3 per capita carbon emissions and per capita carbon footprint in 30provinces 2002(Unit: tonCO2)

3.3 Carbon emissions transfer of interprovincial

Products and services trades between provinces result in carbon emissions transfer of interprovincial, and it's a main factor of the difference of per capita carbon emissions and carbon footprint. The amount of carbon emissions transfer of interprovincial , Hebei,Jilin,Anhui,Zhejiang, Guangdong,Beijing,Tianjin are the most. 7 provinces occupy 52%. Carbon emissions induced by trade is 0.706 billion tons in Hebei， account for 17% of all the provinces. Carbon emissions induced by trade is 4.89 billion tons in Jilin, account for 12% of all the provinces. Guizhou,Guangxi,Jiangxi,Xinjiang,Hainan,Fujian,Qinghai and Heilongjiang are the lowest and the amount of transferred CO2 emissions is less than 8%. The amount of carbon emissions transfer of interprovincial explain further interprovincial trade have a very important impact on carbon footprint and carbon emissions.（Fig. 4）.

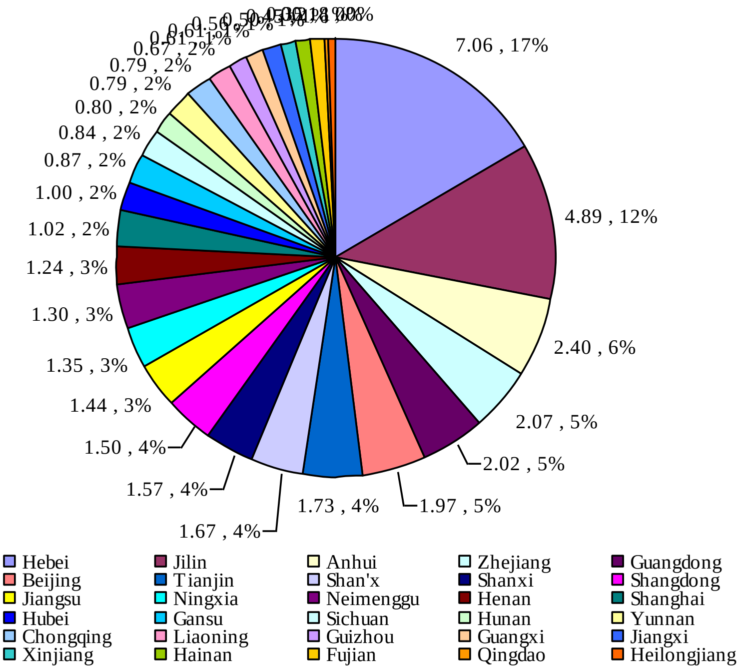

Fig .4 The amount and ratio of interprovincial carbon emissions transfer（Unit：10^8 tonsCO2& %）

The provinces in which the net transferred in CO2 emissions in the goods and service from high to low are: Jilin,Shanghai,Beijing,Shanxi,Hainan,Yunnan,Qinghai,Ningxia,Xinjiang, Heilongjiang,Tianjing,Guangdong,Gansu,Guizhou and Fujian.The provinces in which the net outflow CO2 emissions in the goods and service from low to high are:Henan,Neimenggu, Shandong,Hubei,Hebei,Guangxi,Liaoning,Jiangsu,Shanxi,Sichuan,Zhejiang,Hunan,Chongqin and Anhui.The CO2 emissions implied in the provincial trade mainly has three types:direct energy-intensive products, manufacturing products and the construction, transportation and commercial service.

The provinces result from the direct energy-intensive products are: Jilin,Shanghai, Beijing,Shanxi, Hainan,Yunnan and Anhui.The net inflow in CO2 emissions of Jilin is 191 million tons, which is major in energy-intensive department of cement, glass and ceramic, electricity, heat production, and the automotive and food industry. The net inflow in CO2 emissions of Beijing is 57 million tons, which is resulted from the transfer of electricity, heat , cement and steel.

The provinces which have the net inflow in CO2 emissions are: Qinghai,Ningxia,Xinjiang, Heilongjiang,Tianjin,Gansu and Guizhou. The CO2 emissions from cement and steel of Qinghai is net inflow, while the CO2 emissions from oil and gas mining is net outflow. The net inflow and outflow CO2 emissions from the direct energy-intensive products is almostly balance. The large quantity of the transfer of motor, household applicance and communication production lead the CO2 emissions of Qinghai to be net inflow. The net inflow CO2 emissions from electricity and cement of Ningxia keep the same with the net outflow CO2 emissions from steel, while the transfer of motor, household applicance and communication production and other transport devices from other provinces leads the CO2 emissions to be outflow.

The provinces of the net inflow CO2 emissions from the agriculture and transportation are: Guangdong .In the aspect of commercial independence among provinces，the inflow and outflow CO2 emissions from the direct energy product and manufacturing product is almost the same, but in the aspect of agriculture and transportation ,the inflow CO2 emissions is more than that the outflow CO_2 emissions, that is net inflow.

Among the provinces which have the net outflow CO_2 emissions:

The provinces result from the direct energy-intensive products are:Henan,Neimenggu,Hubei, Heibei,Liaoning,Jiangsu,Jiangxi and Sichuan. The CO_2 emissions of Heinan is net outflow, mainly resulted from transferred out of the large quantity of the metallic mineral products which lead net outflow CO_2 emissions to be 2.49 million tons. A large number transferred out of electricity, heat steel and non-ferrous metal products lead the CO_2 emissions of Neimenggu to be net outflow.

The provinces result from the manufacturing products are: Shanxi and Guangdong. The large quantity transferred out of food processing industry result in 7.89 million tons of CO_2 emissions which is at 41 percentage of the total CO_2 emissions. The transferred out of cement, paper and food processing industry result in 14 million tons of CO_2 emissions, which is at 83 percentage of the total CO_2 emissions.

Table2 CO_2 emissions induced by interprovincial trade and composition（Unit：10^8 tonsCO_2）

Region	The amount of carbon emissions transfer			Carbon emissions transferred by high energy consumption sectors			Carbon emissions transferred by manufacturing			Carbon emissions transferred by building and service industry		
	Outflow	Inflow	Net inflow	Outflow	Inflow	Net inflow	Outflow	Inflow	Net inflow	Outflow	Inflow	Net inflow
Jilin	1.49	3.40	**1.91**	0.61	-1.67	**1.06**	0.61	-1.46	**0.85**	0.11	-0.08	**-0.04**
Shanghai	0.22	0.80	**0.58**	0.00	-0.35	**0.35**	0.17	-0.23	**0.06**	0.04	-0.15	**0.11**
Beijing	0.70	1.27	**0.57**	0.28	-0.64	**0.37**	0.31	-0.46	**0.15**	0.06	-0.07	**0.00**
Shan'xi	0.68	0.98	**0.30**	0.27	-0.71	**0.44**	0.18	-0.20	**0.02**	0.07	-0.03	**-0.04**
Hainan	0.08	0.37	**0.28**	0.02	-0.20	**0.18**	0.04	-0.10	**0.06**	0.01	-0.01	**-0.00**
Yunnan	0.29	0.50	**0.21**	0.14	-0.29	**0.15**	0.10	-0.15	**0.05**	0.04	-0.03	**-0.02**
Qinghai	0.04	0.17	**0.12**	0.03	-0.08	**0.04**	0.00	-0.06	**0.06**	0.00	0.00	**0.00**
Ningxia	0.63	0.72	**0.10**	0.37	-0.36	**-0.01**	0.08	-0.22	**0.15**	0.05	-0.08	**0.03**
Xinjiang	0.20	0.30	**0.09**	0.08	-0.06	**-0.02**	0.05	-0.16	**0.12**	0.02	-0.05	**0.04**
HLJ	0.05	0.13	**0.09**	0.00	-0.03	**0.03**	0.02	-0.09	**0.07**	0.01	0.00	**-0.01**
Tianjin	0.84	0.90	**0.06**	0.32	-0.35	**0.03**	0.29	-0.38	**0.10**	0.15	-0.09	**-0.06**
Guangdong	1.00	1.02	**0.03**	0.36	-0.33	**-0.03**	0.56	-0.54	**-0.02**	0.04	-0.09	**0.05**
Gansu	0.43	0.44	**0.01**	0.37	-0.14	**-0.23**	0.03	-0.15	**0.12**	0.02	-0.01	**-0.01**
Guizhou	0.30	0.31	**0.01**	0.21	-0.18	**-0.03**	0.06	-0.09	**0.03**	0.01	-0.01	**0.01**
Fujian	0.17	0.18	**0.00**	0.07	-0.07	**0.01**	0.08	-0.09	**0.01**	0.01	0.00	**-0.01**
Anhui	1.20	1.20	**-0.01**	0.56	-0.63	**0.07**	0.44	-0.40	**-0.04**	0.05	-0.08	**0.02**
Chongqing	0.40	0.39	**-0.01**	0.18	-0.19	**0.01**	0.16	-0.16	**-0.00**	0.04	-0.02	**-0.02**
Hunan	0.41	0.39	**-0.01**	0.25	-0.27	**0.02**	0.11	-0.09	**-0.02**	0.00	0.00	**0.00**
Zhejiang	1.04	1.02	**-0.02**	0.20	-0.61	**0.42**	0.72	-0.27	**-0.45**	0.08	-0.07	**-0.00**
Sichuan	0.43	0.41	**-0.02**	0.26	-0.21	**-0.05**	0.10	-0.11	**0.01**	0.05	-0.05	**-0.01**
Jiangxi	0.31	0.25	**-0.05**	0.19	-0.10	**-0.08**	0.05	-0.10	**0.05**	0.03	-0.03	**0.00**
Shanxi	0.81	0.75	**-0.06**	0.46	-0.17	**-0.29**	0.01	-0.50	**0.49**	0.06	-0.04	**-0.02**
Jiangsu	0.78	0.65	**-0.13**	0.32	-0.20	**-0.12**	0.43	-0.43	**-0.01**	0.01	0.00	**-0.01**
Liaoning	0.41	0.26	**-0.15**	0.14	-0.06	**-0.08**	0.20	-0.16	**-0.04**	0.02	0.00	**-0.02**
Guangxi	0.39	0.22	**-0.17**	0.15	-0.08	**-0.07**	0.15	-0.06	**-0.09**	0.06	-0.03	**-0.02**
Hebei	3.62	3.44	**-0.18**	1.70	-1.15	**-0.55**	1.17	-1.46	**0.30**	0.26	-0.32	**0.06**
Hubei	0.59	0.41	**-0.19**	0.32	-0.15	**-0.17**	0.18	-0.08	**-0.09**	0.04	-0.06	**0.02**
Shandong	0.84	0.65	**-0.19**	0.32	-0.25	**-0.07**	0.46	-0.33	**-0.13**	0.02	0.00	**-0.02**
Neimenggu	0.78	0.52	**-0.26**	0.65	-0.22	**-0.42**	0.08	-0.27	**0.19**	0.00	0.00	**-0.00**
Henan	0.78	0.46	**-0.33**	0.47	-0.23	**-0.23**	0.17	-0.12	**-0.05**	0.03	-0.02	**-0.00**

3.4 The relationship of interprovincial trade and carbon emissions transfer

Interprovincial carbon emissions transfer is related to economic relations and trade between the provinces. Trade volume of interprovincial is closely correlated with the amount of CO2 emissions, the correlation coefficients of them is 0.79. however, the quantity and quality of trade products in different provinces is varied, and lead the interprovincial carbon emissions transfer to obvious regional changes.Some provinces which carbon emissions induced by trade increased with interprovincial trade surplus, they are Jilin,Shanghai,Beijing,Hainan,Yunnan, Qinghai, Ningxia,Xinjiang, Gansu and Heilongjiang. Provinces which carbon emissions induced by trade increased with interprovincial trade deficit are Shan'xi,Tianjin,Guangdong,Guizhou and Fujian respectively. Provinces which carbon emissions induced by trade decreased with interprovincial trade surplus are Shanxi and Hebei; Provinces which carbon emissions induced by trade decreased with interprovincial trade deficit are Anhui,Chongqnig,Hunan,Zhejiang,Sichuan, Jiangxi,Jiangsu, Liaoning,Guangxi,Hubei,Shandong,Neimenggu and Henan(Fig. 5).

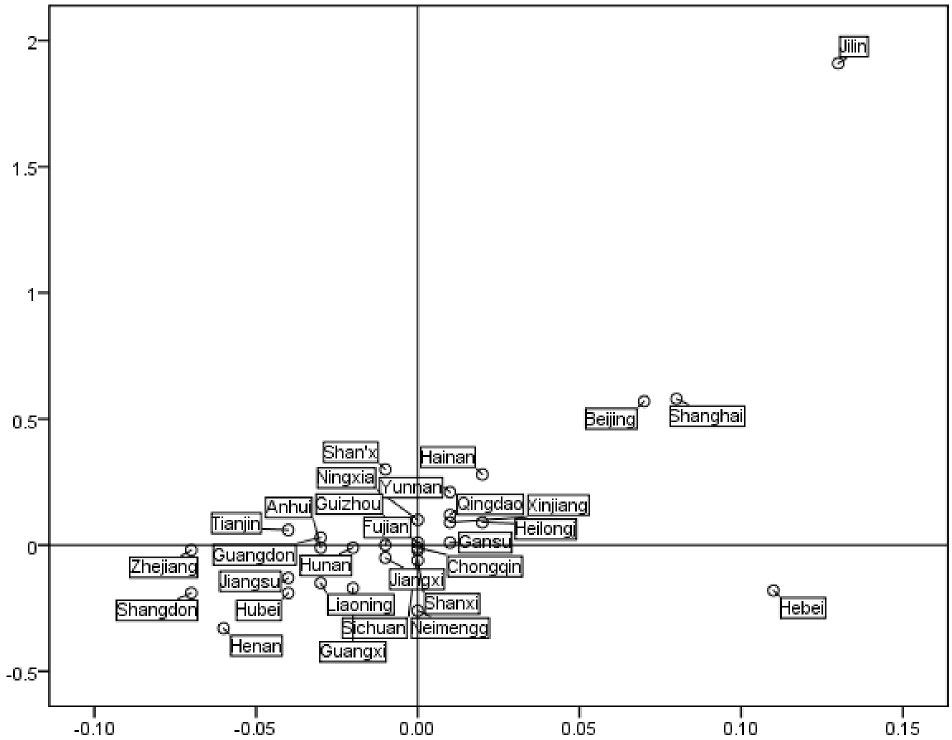

Fig. 5 The relation of net increment of interprovincial trade and CO2 emissions transfer

4. Conclusions and Implications

4.1Conclusions

- There are significant differences of the total amount of carbon footprint among the 30 provinces. The amount of carbon footprint in Shandong province is 16times more than that of Qinghai province. The total amount of carbon footprint are at the highest level in those provinces rich in mineral resources;The total amount of carbon footprint are at moderate level in those economically developed and energy-intensive businesses provinces; The total amount of carbon footprint are at lowest level in those fewer resources, undeveloped manufacturing provinces.

- The difference of per capita CO_2 emissions relate to population, economic level, resources distribution, industrial structure in 30 provinces.The differences in per capita of carbon footprint related to the final demand structure. the carbon footprint is larger in those provinces with high consumption and high investment,especially in those provinces which have strong demands for construction and manufacturing. The carbon footprint is low in those non-resource-based, limited investment and construction provinces.
- Per capita carbon emissions in each province are highly correlated with per capita carbon footprint, in those provinces with high consumption and high investment, per capita CO_2 emissions is lower than per capita CO_2 footprint; in those provinces with rich in mineral resources to the contrary.
- Interprovincial trades have a significant impact on carbon footprint and carbon emissions. CO_2 emissions are net inflow in those provinces which have advanced infrastructure construction, more inflow goods with high energy consumption. CO_2 emissions induced by goods inflow mainly come from metallurgical, chemical, electricity and cement industries. In southwestern provinces, manufacturing is backward to some degree, net inflow CO_2 emissions are caused by trading in the produce of manufacturing industry. The provinces with resource-intensive and manufacture-advanced spill over CO_2.
- The carbon emissions transfer is closely related to the interprovincial economic contacts , but the reason as a result of the differences in resources distributions, industrial structure and the level of economic development in different provinces, some provincesis opposite to the trends, such as in Shanxi, Tianjin, Guangdong, Guizhou and Fujian province trade volume， but CO_2 emissions is the inflow ，in Shanxi and Hebei the trade surplus,CO_2 emissions is the inflow.

4.2 Inspirations

- The analysis of carbon footprint and carbon emissions transfer provide a quantitative reference for setting the targets of Provincial-scale emissions reduction targets, but the specific direct and indirect transfer of CO_2 emissions are not revealed in provinces.Transfer of carbon emissions in provinces is worth further analysis using range of input-output model data.
- In addition, account the carbon footprint and CO_2 emissions transfer induced by transferring in and transferring out, using the same full emissions factor, implying an assumption. Fix and refine the conclusion with the using and developing of input-output model .
- It is great significance that construct input-output optimization model and situational simulation under the constraint of low-carbon targets, It can provide the theory basis and the scientific references for the policy of regional emission reduction.

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