Regional Differences and Dynamic Evolution of CO2 Emissions Distribution in China’s Construction Industry

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Abstract. Based on the panel data of 30 provinces in China from 1997 to 2015, this paper uses Dagum Gini coefficient and decomposition method to study the regional differences and sources of China’s construction industry CO2 emissions, meanwhile uses Kernel density estimation method to analyze the dynamic evolution of its distribution in four regions. Research results show that: The regional difference of China's construction industry CO2 emissions shows a trend of first rising and then declining, and the main source of regional differences is inter-regional differences. The absolute differences of China's construction industry CO2 emissions are narrowing, and the weak polarization and gradient effect of the distribution of CO2 emissions gradually disappear. These results have important implications for the coordinated low-carbon development of China’s construction industry.

1. Introduction

The excessive emission of greenhouse gases in recent years, mainly CO2, has caused a series of serious environmental problems. Global awareness of reducing carbon emissions is growing with the increasing signs of CO2 impact on the climate. As the largest CO2 emitter in the world, China has become the focus of the global carbon emission reduction plan with the increasing international pressure. With the continuous development of social and economy, the carbon emission caused by the energy consumption in the process of the prosperity of the construction industry is very serious, which can’t be ignored. According to statistics, greenhouse gas emission of construction industry accounts for more than 40% of various industries greenhouse gas emissions of in China. Controlling the carbon emission of construction industry has become a vital work to early realize the target of carbon emission reduction in China. China is vast in territory and the CO2 emissions of the construction industry vary greatly across regions. Therefore, it is necessary to study regional differences and dynamic evolution of construction industry CO2 emission distribution in China, and to understand the current situation of construction industry carbon emissions in China. In this way, we can put forward more scientific and reasonable policy recommendations for China's construction industry carbon emission reduction, and make targeted energy conservation and emission reduction policy guidance according to the characteristics of the construction industry in each province.

The related issues of CO2 emissions in construction industry have received widespread attention in academic circles with people's emphasis on environmental pollution. However, the existing literature on CO2 emission of construction industry focuses on its calculation[1-3] and analysis of influencing factors[4-6], and rarely further analyzes the regional differences and dynamic evolution of CO2 emission of construction industry. In view of the limitations of the existing literature, this paper expands the existing research from the following aspects: (1) Collect the panel data of construction industry CO2 emissions in China’s 30 provinces from 1997 to 2015; (2) Dagum Gini coefficient and its
decomposition method are used to reveal the regional differences in the distribution of CO₂ emissions in China's construction industry, and to explore the main sources of regional differences; (3) Kernel density estimation method are used to study the dynamic evolution trend of the distribution of CO₂ emissions in China's construction industry, and reveal the temporal and spatial evolution law of the construction industry CO₂ emissions distribution in China; (4) We summarizes the conclusions of the previous analysis, and put forward corresponding countermeasures and suggestions to advance the space coordination development of China's construction industry under the framework of energy conservation and emission reduction policies.

2. Methodology Specification and Data Description

2.1. Research Method

2.1.1. Dagum Gini Coefficient. Dagum Gini coefficient proposed by Dagum[7] decomposes the total Gini ratio between of a group into the contribution of the Gini inequality within subgroups, the net contribution of the Gini inequality between subgroups and the contribution of the intensity of transvariation between subgroups. This decomposition method effectively solves the problems of regional difference sources and overlapping of sample data. The definition of Gini coefficient is as follows the equation (1), where \( y_{ji}(y_{hr}) \) is the construction industry CO₂ emissions in any province of \( j \) (\( h \)) region, \( \mu \) indicates the average CO₂ emission of construction industry in 30 provinces, \( n \) represents the number of provinces is 30, \( k \) indicates that the number of areas divided is 4, \( n_j \) \( (n_h) \) is the number of provinces in \( j \) \( (h) \) region. Equation (2) refers to sorting the average CO₂ emissions of construction industry in each region before the decomposition of Gini coefficient, equation (3) shows that the Gini coefficient \( G \) can be divided into the following three components: the contribution of the Gini inequality within regions \( (G_w) \), the net contribution of Gini inequality between regions \( (G_{nb}) \) and the contribution of the intensity of transvariation between regions \( (G_t) \), \( G_w, G_{nb} \) and \( G_t \) are calculated by equations (4), (5) and (6) respectively. Equation (7) shows the Gini coefficient of the region \( j \) is \( G_{jj} \), and equation (8) means the Gini coefficient between regions of \( j \) and \( h \) is \( G_{jh} \), where \( p_j = n_j / n, s_j = n_j \mu_j / (n \mu), j = 1,2, \ldots, k \). \( D_{jh} \) represents the relative difference of CO₂ emissions of construction industry between regions \( j \) and \( h \), 1-\( D_{jh} \) means the intensity transvariation. \( D_{jh} \) can be calculated by equation (9), where \( d_{jh} \) indicates that the differences in CO₂ emissions of construction industry between regions \( j \) and \( h \) when \( y_{ji} > y_{hr} \), and \( p_{jh} \) means the transvariation first moment in CO₂ emissions of construction industry between regions \( j \) and \( h \) when \( y_{ji} < y_{hr} \). The calculation formulas of \( d_{jh} \) and \( p_{jh} \) are as equation (10) and equation (11), while \( F_j(F_h) \) represent the cumulative distribution function of \( j \) \( (h) \) region.

\[
G = \frac{\sum_{j=1}^{k} \sum_{h=1}^{k} \sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{2n^2 \mu} \quad (1)
\]
\[
\mu_h \leq \mu_j \leq \cdots \leq \mu_k \quad (2)
\]
\[
G = G_w + G_{nb} + G_t \quad (3)
\]
\[
G_w = \sum_{j=1}^{k} G_{j} p_j s_j \quad (4)
\]
\[
G_{nb} = \sum_{j=2}^{k} \sum_{h=1}^{k-1} G_{jh} \left( p_j s_h + p_h s_j \right) D_{jh} \quad (5)
\]
\[
G_t = \sum_{j=2}^{k} \sum_{h=1}^{k-1} G_{jh} \left( p_j s_h + p_h s_j \right) \left( 1 - D_{jh} \right) \quad (6)
\]
\[
G_{ji} = \frac{\sum_{i=1}^{n_j} \sum_{j=1}^{n_j} |y_{ji} - y_{ji}|}{2\mu_j n_j^2}
\]

(7)

\[
G_{jh} = \frac{\sum_{i=1}^{n_j} \sum_{j=1}^{n_h} |y_{ji} - y_{jh}|}{(\mu_j + \mu_h)n_j n_h}
\]

(8)

\[
D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}}
\]

(9)

\[
d_{jh} = \int_0^\infty dF_j(y)\int_0^y (y-x) dF_h(x)
\]

(10)

\[
p_{jh} = \int_0^\infty dF_h(y)\int_0^y (y-x) dF_j(y)
\]

(11)

2.1.2. Kernel Density Estimation. Kernel density estimation is used to estimate the unknown density function and describe the dynamic distribution of random variables by continuous density curve, which is one of the nonparametric test methods. Suppose \( f(x) \) is the density function of random variable \( x \):

\[
f(x) = \frac{1}{Nh} \sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right)
\]

(12)

where \( K(\cdot) \) is the kernel function, \( N \) is the number of observations, \( X_i \) indicates the independent and identically distributed observations, \( x \) is the mean of observations, \( h \) is the bandwidth. The results of kernel density estimation are sensitive to bandwidth, and the accuracy will increase with the decrease of bandwidth. Therefore, scholars usually choose the bandwidth as small as possible. Kernel function is a kind of weighting function or smoothing function, and the Gaussian kernel function commonly used in application is selected in this paper to estimate the dynamic evolution of \( CO_2 \) emissions distribution in China's construction industry. The Gaussian kernel function formula is as follows:

\[
K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)
\]

(13)

We can get the kernel density model which is finally used in empirical research by substituting formula (13) into formula (12):

\[
f(x) = \frac{1}{Nh} \sum_{i=1}^{N} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{||X_i - x||^2}{2h^2}\right)
\]

(14)

The results of kernel density estimation can reflect information about the location, shape and ductility of the distribution of variables. The distribution location reflects the level of regional \( CO_2 \) emissions; the distribution form is used to analyze the spatial difference and polarization degree of \( CO_2 \) emissions, in which the height and width of wave crest reflect the absolute difference, and the number of wave crest reflects the degree of polarization; the distribution ductility can describe the regional difference between the province with the highest \( CO_2 \) emissions level of construction industry and other provinces, and the longer the tail, the greater the difference[8].
2.2. Regional Division and Data Source

Referring to the regional division method of the National Bureau of statistics, distribution of the 30 provinces in the four regions of China is as follows. Eastern: Beijing, Shanghai, Tianjin, Hebei, Shandong, Jiangsu, Fujian, Zhejiang, Guangdong and Hainan; central: Shanxi, Henan, Anhui, Jiangxi, Hubei and Hunan; western: Inner Mongolia, Shaanxi, Guangxi, Chongqing, Yunnan, Sichuan, Gansu, Qinghai, Ningxia, Guizhou and Xinjiang; Northeast: Jilin, Liaoning and Heilongjiang. Tibet, Taiwan, Hong Kong and Macao are not included in the study due to the serious lack of related data. China provincial construction industry CO₂ emission panel data (1997–2015) are obtained from China Emission Accounts and Datasets (CEADs). Figure 1 shows the trend of the average annual of CO₂ emissions of construction industry in four regions of China from 1997 to 2015.

![Figure 1. The trend of the average annual of CO₂ emissions of construction industry in four regions of China from 1997 to 2015.](image)

3. Regional Differences and Sources of CO₂ Emissions

We use Dagum Gini coefficient and its decomposition method to investigate the regional differences and sources of CO₂ emissions in China's construction industry.

3.1. The Overall Regional Differences

According to Table 1, the overall difference of CO₂ emissions in China’s construction industry is relatively large, and the Gini coefficient is between 0.3107-0.6246. The overall difference of CO₂ emission of construction industry in China shows a fluctuating trend of "up-down-up-down" from 1997 to 2015. Table 1 further reveal the magnitude and trends of the intra-regional differences in CO₂ emissions from construction industry in four regions. Overall, the regional differences in northeast and eastern are rising first and then declining, while the regional differences in western and central are declining.

| Year | Overall | East | Central | West | Northeast |
|------|---------|------|---------|------|-----------|
| 1997 | 0.3563  | 0.1657| 0.2241  | 0.1891| 0.1071    |
| 1998 | 0.4314  | 0.2718| 0.2348  | 0.1928| 0.1389    |
| 1999 | 0.4731  | 0.3086| 0.2216  | 0.1879| 0.1333    |
| 2000 | 0.4040  | 0.2747| 0.2330  | 0.1736| 0.1282    |
| 2001 | 0.4525  | 0.2907| 0.2141  | 0.2175| 0.1806    |
| 2002 | 0.4810  | 0.3236| 0.2337  | 0.2022| 0.1795    |
| 2003 | 0.6246  | 0.2371| 0.2276  | 0.2128| 0.3095    |
| 2004 | 0.3698  | 0.1929| 0.2288  | 0.2059| 0.1724    |
| 2005 | 0.3575  | 0.1948| 0.2060  | 0.1838| 0.1574    |
| 2006 | 0.3439  | 0.1833| 0.2115  | 0.1810| 0.1624    |
| 2007 | 0.3647  | 0.1853| 0.2121  | 0.2039| 0.1545    |
3.2. Sources of Regional Differences

The regional differences sources of China's construction industry CO$_2$ emissions are showed in Table 2 and Figure 2. The inter-regional differences include the net contribution of Gini inequality between regions ($G_{nb}$) and the contribution of the intensity of tranvariation between regions ($G_t$). It can be seen that the inter-regional differences are the main source of the construction industry CO$_2$ emissions imbalance distribution, and the average contribution of the inter-regional differences is 84.77%. From 1997 to 2003, $G_{nb}$ and $G_t$ alternated up and down repeatedly; $G_t$ is higher than $G_{nb}$ from 2004 to 2011, indicating the cross influencing factors of regional development during this period were responsible for imbalance distribution of CO$_2$ emissions in China's construction industry; $G_{nb}$ exceeds $G_t$ since 2012, which means that the gap of net value of the construction industry CO$_2$ emissions among different regions is relatively large in recent years, and causing China's construction industry CO$_2$ emissions are unevenly distributed. The average contribution rate of intra-regional differences is 15.23%, and the trend is relatively stable, ranging from 8.17% to 16.95%. It indicates that the differences of construction industry CO$_2$ emissions among provinces of each region have the least impact on the uneven distribution of China's construction industry CO$_2$ emissions.

### Table 2. The sources of regional differences and their contribution rate.

| Year | Intra-regional differences | The net value of transvariation between regions | The intensity of transvariation between regions |
|------|---------------------------|---------------------------------------------|---------------------------------------------|
|      | Sources $G_s$ (%)         | Sources $G_{nb}$ (%)                         | Sources $G_t$ (%)                           |
| 1997 | 0.0494                    | 0.1375                                      | 0.1693                                      | 47.53                                      |
| 1998 | 0.0689                    | 0.1465                                      | 0.2159                                      | 50.04                                      |
| 1999 | 0.0775                    | 0.2216                                      | 0.1740                                      | 36.78                                      |
| 2000 | 0.0659                    | 0.0870                                      | 0.2511                                      | 62.16                                      |
| 2001 | 0.0764                    | 0.1820                                      | 0.1941                                      | 42.90                                      |
| 2002 | 0.0815                    | 0.1696                                      | 0.2299                                      | 47.79                                      |
| 2003 | 0.0510                    | 0.4146                                      | 0.1591                                      | 25.47                                      |
| 2004 | 0.0593                    | 0.0334                                      | 0.2771                                      | 74.92                                      |
| 2005 | 0.0553                    | 0.0994                                      | 0.2028                                      | 56.73                                      |
| 2006 | 0.0540                    | 0.0834                                      | 0.2065                                      | 60.05                                      |
| 2007 | 0.0560                    | 0.0962                                      | 0.2124                                      | 58.25                                      |
| 2008 | 0.0518                    | 0.0943                                      | 0.1753                                      | 54.54                                      |
| 2009 | 0.0494                    | 0.1183                                      | 0.1558                                      | 48.16                                      |
| 2010 | 0.0560                    | 0.0922                                      | 0.1972                                      | 57.09                                      |
| 2011 | 0.0523                    | 0.1126                                      | 0.1711                                      | 50.92                                      |
| 2012 | 0.0488                    | 0.1324                                      | 0.1295                                      | 41.68                                      |
| 2013 | 0.0486                    | 0.1450                                      | 0.1312                                      | 40.38                                      |
| 2014 | 0.0481                    | 0.1678                                      | 0.1133                                      | 34.42                                      |
| 2015 | 0.0471                    | 0.1989                                      | 0.0967                                      | 28.22                                      |
4. Analysis of the Dynamic Evolution of CO₂ Emissions
We use kernel density estimation method to discuss the location, shape, ductility and polarization trend of the distribution of CO₂ emissions in China's construction industry. Figure 3 shows the kernel density estimation results of construction industry CO₂ emissions in China from 1997 to 2015, we can see that the dynamic evolution of CO₂ emissions distribution mainly embodies three characteristics: (1) The central location of the kernel density curve shows a trend of right shift, which means that the total CO₂ emission of China's construction industry is increasing year by year. (2) On the whole, the height of the wave peak is gradually higher, the width of the wave crest decreases gradually, and the right tail becomes shorter, which indicates that the absolute difference of CO₂ emissions between the provinces is decreasing year by year, and the number of provinces with high CO₂ emissions in construction industry are decreasing year by year. (3) In the early years during the sample observation period, the kernel density curve shows double peaks, and the side peak is relatively low. The kernel density curve gradually evolves into a single peak as time goes by. These trends mean that the distribution of CO₂ emissions showed a weak polarization in the previous years, with a certain gradient effect, and the polarization phenomenon disappeared in recent years.

5. Conclusions and Policy Implications
Using the panel data of 30 provinces from 1997 to 2015, this paper analyses regional differences and dynamic evolution of construction industry CO₂ emissions in the eastern, central, western and northeast of China by using Dagum Gini coefficient decomposition method and kernel density estimation method. Research conclusions are as follows: (1) There are obvious regional differences in China’s construction industry CO₂ emissions. Specifically, eastern and central regions are the key areas of CO₂ emission of China's construction industry, which are at a higher level as a whole, western
region are at a lower level as a whole, and northeast region fluctuates greatly. (2) From the perspective of relative differences reflected by Dagum Gini coefficient, the overall regional difference of CO₂ emission in China's construction industry increases first and then decreases, and the intra-regional differences in northeast and eastern regions are rising first and then declining, while the regional differences in western and central regions are declining. On the whole, inter-regional difference is the main source of CO₂ emission distribution imbalance in China’s construction industry. (3) From the perspective of absolute difference revealed by kernel density estimation, CO₂ emissions in China's construction industry is increasing year by year, while the regions with high CO₂ emission decrease year by year. The absolute difference of CO₂ emissions in China's construction industry shows a decreasing trend, and weak polarization and gradient effect of CO₂ emission distribution gradually disappear.

Based on the research results, the following suggestions are put forward to promote low-carbon development of construction industry: (1) All regions should strengthen adjustment of economic structure according to their own development, perfect construction market, strengthen macroeconomic regulation and control, establish the government incentive mechanism, and ensure healthy and sustainable development of construction industry. (2) Increase research and development of building energy saving technology and training of relevant talents, taking lead in optimizing the development of eastern and central regions leading by innovation, and establish a more effective new mechanism for regional coordinated development. (3) The regional transfer of the construction industry should be put into force and accelerate cross regional flow of technology, talent, capital and other elements at the same time, which can promote the coordinated low-carbon development of construction industry.

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