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Inequality of Carbon Intensity: Empirical Analysis of China 2000–2014

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Abstract: On the 3 September 2016, China officially ratified the Paris agreement as the main global producer of carbon emissions. A key of China's commitment is to reduce its carbon intensity by 60–65% between 2005 and 2030. An improved understanding of the inequality of carbon intensity at national-, inter-regional-, and intra-regional scale is a prerequisite for the development of a more cost-effective carbon intensity reduction policy. In this study, we used the Dagum Gini coefficient and its subgroup decomposition method to quantify China's inequality of carbon intensity between 2000 and 2014 based on available and updated data. The results show: (i) The Gini coefficient indicates a rising inequality of the carbon intensity at both national and sub-national scale, suggesting accelerated inequality of carbon intensity at national-, inter-regional, and intra-regional-scale. (ii) The Gini coefficient indicates a rising trend of intra-regional carbon intensity in Central and Western China, while the trend declines for Eastern China. (iii) The Gini coefficient indicates rising carbon intensity between Eastern and Central China, Western and Eastern China, and Central and Western China. (iv) Transvariation intensity occupies a leading role in the increasing national-level carbon intensity Gini coefficient. Ultimately, several policy recommendations are provided.

Keywords: carbon intensity; disparity; Dagum Gini coefficient; national and sub-national level; China

1. Introduction

On the 3 September 2016, China as the main global producer of carbon emission, announced its ratification of the Paris climate change agreement [1], thus paving the way many other countries to follow suit. A key of China's commitment is to reduce its carbon intensity (defined as carbon dioxide emissions per unit of GDP) by 60–65% of the 2005 level by the end of 2030 [2,3]. Implementing this commitment requires a total restructuring of Chinese energy consumption [4,5]. It furthermore requires the optimization of its economic structure [6,7]. However above all, this commitment requires the development of a more cost-effective policy to reduce carbon intensity [8,9]. An improved understanding of carbon intensity inequality at national-, inter-regional, and intra-regional scale is a necessary prerequisite for the development of an effective policy to reduce carbon emission.

The Gini coefficient is a versatile method to analyze inequality issues [10–13]. Dagum developed a Gini coefficient and a subgroup decomposition technique, which allowed the Gini coefficient method to be used for spatial decomposition [14,15]. Dagum's Gini coefficient and its subgroup decomposition technique can decompose regional differences into intra-regional differences, inter-regional net differences, and an intensity of transvariation intensity. Therefore, Dagum's Gini coefficient method has been used to study the inequality of energy and carbon emission issues [16–21]. In this study, we utilized the Gini coefficient and its subgroup decomposition method to investigate disparities of carbon intensity in China between 2000 and 2014, based on available and updated data.

2. Literature Review

Carbon dioxide emission inequality exists throughout various regions, which is considered to be an outstanding problem for all affected countries and places. Most previous studies focused on differences between countries [17,22–29] instead of analyzing one specific country. However, an analysis on nation-state level is more applicable to a specific region, since the discussions are based on the character of the studying area. This can also shed light on the specific problems caused by changes of carbon dioxide emission.

Moreover, most of the studies related to CO_2 problems were mainly about carbon dioxide emission. Fu and Yang analyzed spatial structures and evolution of networks by examining geographic characteristics of selected renewable energy trades and their evolution, based on data from the United Nations COMTRADE Database, ranging from 1988 to 2013 [30]. Grunewald and Jakob discussed the evolution of inequality in global CO_2 per-capita emissions, using both historical data of energy-related CO_2 emissions and future emission scenarios generated with the integrated assessment model REMIND [31]. Hübler utilized simultaneous-quantile regressions with per capita CO_2 emissions as a dependent variable, thus testing this negative nexus with country-level panel data. The conclusion was that although this supports the negative inequality-emissions (energy) nexus, regressions with fixed-effects in fact question this; therefore, international trade and international investments are predominantly positively related to energy-related emissions [32]. Jorgenson and Schor investigated the relationship between U.S. state-level CO_2 emissions and two measures of income inequality: the income share of the top 10% of the population and the Gini coefficient, each of which focused on unique characteristics of income distributions, used to evaluate different analytical approaches [33]. Mussini and Grossi used a three-term decomposition of the changes that occur in the Gini index of per capita CO_2 emissions when moving from an initial to a final per capita CO_2 emission distribution to reveal effects of changes CO_2 emission inequality over time depending on country ranking and per capita CO_2 emissions [18]. Padilla and Duro analyzed the evolution of inequality for CO_2 emissions per capita of the European Union by decomposing the Theil index of inequality into contributions of different factors. The decomposition based on the Kaya formula was applied to the inequality between and within groups of countries, thus comparing the change of inequality caused by the energy intensity factor [34]. Remuzgo and Sarabia analyzed determining factors of inequality in the global distribution of carbon dioxide emissions of different regions by applying factorial decomposition of the second Theil index of inequality. Moreover, the carbon dioxide emission, which was based on Kaya factors, was decomposed into four factors, indicating that global inequality in CO_2 emissions dropped by 22% between 1990 and 2010, while economic growth in terms of labor productivity was revealed as the main factor responsible for the inequality value [35].

Based on these previous studies, we conducted a study about the inequality; however, we concentrated more on the inequality of carbon intensity to uncover more information on the carbon intensity of China, providing more support information for China [36–38] to reduce carbon emissions.

3. Methodology and Data

3.1. Methodologies

The Gini coefficient developed by Corrado Gini as a way to quantify [39,40] and frequently used index to determine the difference of income distribution in economics [41,42], representing the distribution of social wealth in the static surface [43,44]. Standard application of the Gini coefficient is to show income distribution across groups through time [45]. Recently, the Gini coefficient has been extended to measure disproportionality in energy resources [46], inequality in plant size or fecundity, as well as spatial distributions of different land types [39]. With the increasing prominence of carbon equity, carbon Gini coefficient as an effective measurement tool for the equality of carbon emissions has been widely applied in recent years [23,29,47]. Informed by Dagum [14,15] and inspired by further studies [48–51], the carbon intensity Gini coefficient G can be expressed as

$$G = \frac{\sum_{j=1}^{k}\sum_{h=2}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{hr}|}{2n^2\overline{Y}} \tag{1}$$

$$\overline{Y}_h \leq \ldots \overline{Y}_J \leq \ldots \leq \overline{Y}_k \tag{2}$$

where y_{ji} (y_{hr}) is the carbon intensity of a province in the region *j(h)*, $\overline{Y}$ is the average carbon intensity of all provinces in the country, and n_j (n_h) is the number of provinces in region *j(h)*.

Also informed by Dagum [14,15], the carbon intensity Gini coefficient G can be decomposed into three parts: the intra-regional Gini coefficient (G_w), the inter-regional Gini coefficient (G_{nb}), and the Trans-variation intensity (G_t): $G = G_w + G_{nb} + G_t$. The Gini coefficient of the inter-region j can be expressed as

$$G_{jj} = \frac{\frac{1}{2\overline{Y}_j}\sum_{i=1}^{n_j}\sum_{r=1}^{n_j}|y_{ji} - y_{jr}|}{n^2{}_j} \tag{3}$$

where G_{jj} is the Gini coefficient of the j-th sub-national and $\overline{Y}_j$ is the average carbon intensity of all the provinces in the j-th sub-national. The contribution of the inter-regional Gini coefficient to the national-level Gini coefficient can be expressed as

$$G_w = \sum_{j=1}^{k} G_{jj}P_jS_j \tag{4}$$

where G_w is the contribution of the inter-regional Gini coefficient; P_j and S_j follows lead to that $P_j = n_j/n$, $S_j = n_j\, Y_j/nY$, $j = 1, 2, \ldots, k$. The Gini coefficient in the intra-region j can be expressed as

$$G_{jh} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{hr}|}{n_jn_h(\overline{Y}_j + \overline{Y}_h)} \tag{5}$$

where G_{jh} is the gap of the Gini coefficient between the j sub-national area and the h sub-national area, the contribution of the intra-regional Gini coefficient to the national-level Gini coefficient can be expressed as

$$G_{nb} = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(P_jS_h + P_hS_j)D_{jh} \tag{6}$$

where G_{nb} is the contribution of the intra-regional Gini coefficient to the national-level Gini coefficient.

$$G_t = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(P_jS_h + P_hS_j)\left(1 - D_{jh}\right) \tag{7}$$

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \tag{8}$$

$$d_{jh} = \int_0^\infty dF_j(y)\int_0^y (y-x)dF_h(x) \tag{9}$$

$$P_{jh} = \int_0^\infty dF_h(y)\int_0^y (y-x)dF_j(y) \tag{10}$$

where F_j (F_h) is the h-th (j-th) sub-national cumulative distribution function; d_{jh} is the gross economic affluence between the j-th and the h-th sub-national, such that $\overline{Y}_j > \overline{Y}_h$, d_{jh} is by definition a weighted average of the income difference, $y_{ji} - y_{hr}$ for all income y_{ji} of members belonging to the j-th sub-national with carbon intensities above y_{hr} of members belonging to the h-th sub-national, i.e., $\overline{Y}_j > \overline{Y}_h$, P_{jh} is a first-order moment of transvariation between the j-th and the h-th subpopulations, such that $Y_j > \overline{Y}_h$ is by definition the weighted average of the income difference, $y_{hr} - y_{ji}$ for all pairs of economic units, one taken from the h-th and the other from the j-th subpopulations; i.e., $\overline{Y}_{hr} > \overline{Y}_{ji}$ and $\overline{Y}_j > Y_h$. The word transvariation stands for the differences in income that are considered to have opposite sign than the difference in the means of their corresponding subpopulations.

3.2. Data Source

Carbon dioxide emissions data in previous studies (e.g., [52–59]) were supplied by the Carbon Dioxide Information Analysis Center (CDIAC) of the Oak Ridge National Laboratory, U.S. Department of Energy [60]. Given that CDIAC provides national-level data of carbon emission, the provincial-level carbon emission data in those studies were estimated according to the percentage of the provincial energy consumption of China's total energy consumption. This approach contains significant uncertainty. In this study, national-level and provincial-level carbon emission data come from the China Emission Accounts and Datasets (CEADs), which provide Chinese national and provincial carbon emissions (http://www.ceads.net/) [61–63]. Data of energy consumption and gross domestic production (GDP) stem from the China Energy Statistical Yearbook and the China Statistical Yearbook, respectively. The real GDP used in this paper used a constant price of 2000 RMB. Carbon intensity was expressed in units of carbon dioxide per RMB 10,000 GDP in 2000 constant prices.

4. Analysis Results and Discussion

4.1. National-Level Carbon Intensity Gini Coefficient

The trend of the Gini coefficient of carbon intensity in China from 2000 to 2014 is shown in Figure 1. The Gini coefficient of carbon intensity increased due to a compound annual growth rate of 2.58%, suggesting an increasing difference of carbon intensity between various provinces in China. As shown in Figure 1, the trend of the Gini coefficient of carbon intensity can be divided into two phases:

Phase I (2000–2006): The Gini coefficient of carbon intensity increased with fluctuations during the first phase; in particular, the Gini coefficient decreased from 2000 to 2001, followed by a rapid increase from 2001 to 2004, and a final increase from 2004 to 2006.

Phase II (2007–2013): the Gini coefficient of carbon intensity increased steadily from 0.34 in 2007 to 0.49 in 2014. Furthermore, the compound annual growth rate of the Gini coefficient of carbon intensity reached 5.43% per year between 2007 and 2014, whereas the compound annual growth rate was only 0.19% per year between 2000 and 2006.

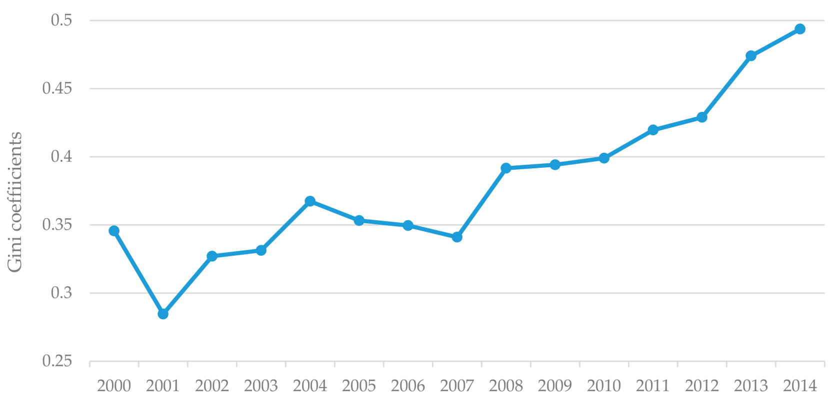

Figure 1. Trajectory of national-scale carbon intensity Gini coefficients.

The increase in national-level carbon intensity Gini coefficient might be related to the increase in difference of provincial-level carbon intensity. The difference between the province with the most-intensive carbon intensity and the province with the least-intensive carbon intensity increased from 0.07616 kg/yuan in 2000, increasing to 0.1542 kg/yuan in 2007 and 0.2027 kg/yuan in 2014. In 2014, the top five provinces with the most-intensive carbon intensity were Shan Xi province, Ningxia Hui Autonomous Region, The Xinjiang Uygur Autonomous Region, Inner Mongolia Autonomous Region, and Gui Zhou Province, whereas the bottom five provinces with the least carbon intensity were Beijing City, Shanghai City, Guangdong Province, Fujian Province, and Jiangsu Province; respectively. The change of carbon intensity in these top and bottom provinces are shown in Figure 2. Industrial structure resulted the big difference of carbon intensity among the different provinces in China, the developed regions are focused on the lower-intensive industries like high-tech industry and modem service industry, which can emission less carbon to obtain relatively more economic output. In contrast, underdeveloped regions are focused on the high-intensive industries like traditional manufacturing industry, which will emit more carbon to obtain a relatively lower GDP. For example, the Hainan province is tourism-dependent, and Shanghai, Beijing, Guangdong, Chongqing are mostly focused on high-tech industry. In addition, the industry transfer has accolated the difference between the different regions, the industry transfers from the East to West and Center are focused on high-carbon industry, for example mining industry, chemical industry, electric coal water production and supply industry, non-metallic mineral products industry, metal smelting, and products industry.

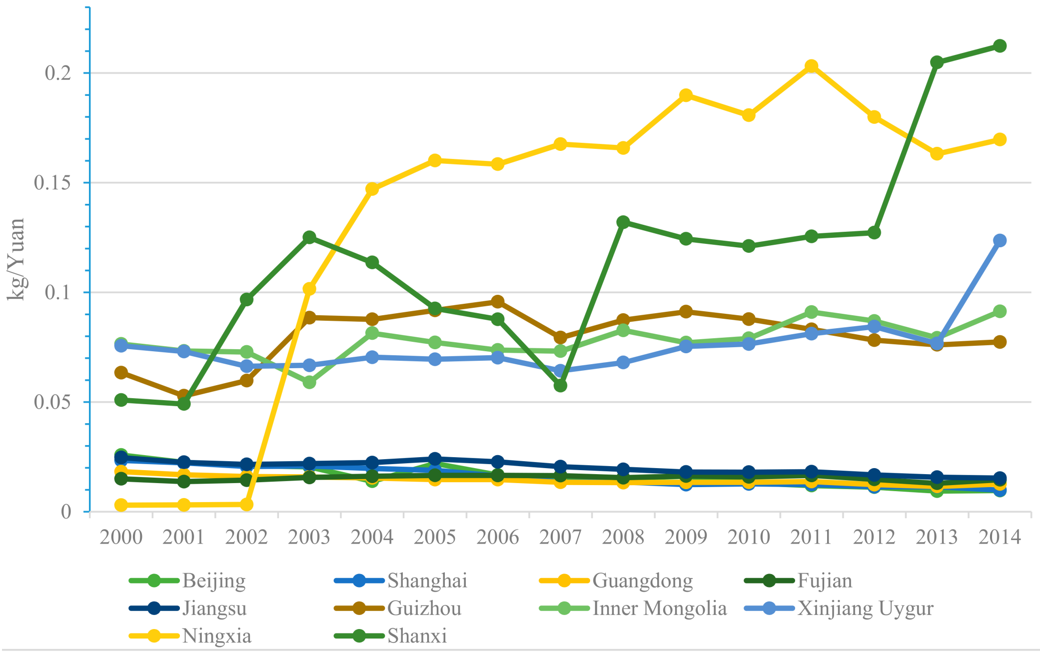

Figure 2. Carbon intensity of selected provinces in China during 2000–2014.

4.2. Sub-National-Level Carbon Intensity Gini Coefficient

China's National Development and Reform Commission, which is the country's top economic planner and guardian, has divided China into three economic-geographic regions based on economic performance and geographical location. These three economic-geographic regions are Eastern China, Central China, and Western China. Eastern China includes the following 11 provincial-level areas: Beijing, Tianjin, Shanghai, Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, and Hainan. Central China includes the following eight provincial-level areas: Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi, Jilin, and Heilongjiang. Western China includes the following 11 provincial-level areas: Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Sichuan, Chongqing, Guizhou, Yunnan, Inner Mongolia, and Guangxi. These three economic-geographic regions have been widely used in numerous studies [64–71]. To further understand China's inequality of carbon intensity, we calculated the Gini coefficients for Eastern China, Central China, and Western China.

4.2.1. Intra-Regional Carbon Intensity Gini Coefficient

Figure 3 shows intra-regional differences of the carbon intensity Gini coefficient for Eastern China, Central China, and Western China. The trajectory of the intra-regional carbon intensity Gini coefficient is rising for Eastern China, declining for Central China, and rising for Western China. To be specific, the carbon intensity Gini coefficient of Eastern China fluctuated from 2000 to 2004, then steadily declined from 2004 to 2011, and finally followed a slight increase from 2011 to 2014. In Central China, the carbon intensity Gini coefficient first increased from 2000 to 2004 and then decreased from 2004 to 2007, finally increasing from 2007 to 2014. In Western China, the carbon intensity Gini coefficient decreased from 2000 to 2003, and then sharply increased from 2003 to 2004, further increasing steadily from 2004 to 2011, and finally reaching a stable plateau from 2001 to 2014. The inequality of the intra-regional carbon intensity Gini coefficient in Eastern China was most pronounced, followed by Central China, and Western China in 2000. However, the inequality of intra-regional carbon intensity of Central China has become the leader, followed by Central China, and Eastern China in 2014.

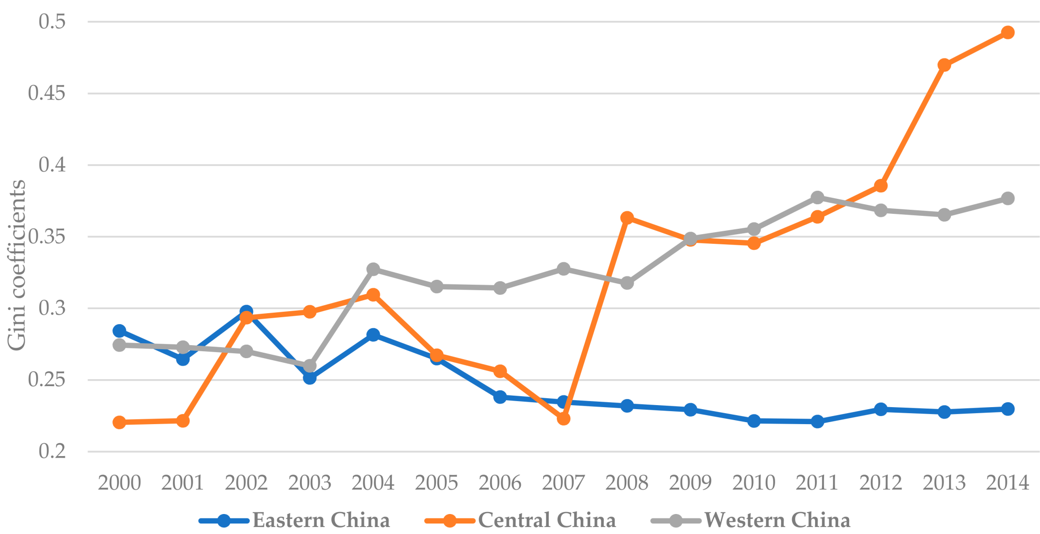

Figure 3. Trajectories of equality of intra-regional carbon intensity Gini coefficient.

Our findings (Figure 3) are similar to those of previous studies. Previous study reported that the difference in carbon intensity in Central China was the largest, followed by Western China and Eastern China [72]. These trajectories of intra-regional carbon intensity Gini coefficient may be related to industrial transfer. Some energy-intensive and carbon-intensive industrial sectors were relocated to some provinces of energy resource enrichment in Central China. Economic growth and carbon emission in those provinces thus were accelerated. However, the accelerating economic growth and carbon emission might not occur in other provinces with poor energy resources. As a result, the intra-regional carbon intensity Gini coefficient in Central China became largest during the study period. In Eastern China, the service industry has gradually become the largest industry. As we know, the service is less-carbon-intensive, the difference of carbon intensity among provinces in Eastern China thus decreased. As a result, the intra-regional carbon intensity Gini coefficient declined. With the implementation of the western development strategy, the difference of economic growth rate and carbon emission among provinces in Western China gradually increased. To be more special, the difference of carbon intensity in the southwest region is greater than that in the northwest region [73]. Thus, the intra-regional carbon intensity Gini coefficient increased.

4.2.2. Inter-Regional Carbon Intensity Gini Coefficient

Figure 4 displays trajectories of the inter-regional carbon intensity Gini coefficient. As shown in Figure 4, the inter-regional carbon intensity Gini coefficient was highest between Eastern China and West China, followed by Eastern China and Central China, and Central China and Western China both in 2000 and in 2014.

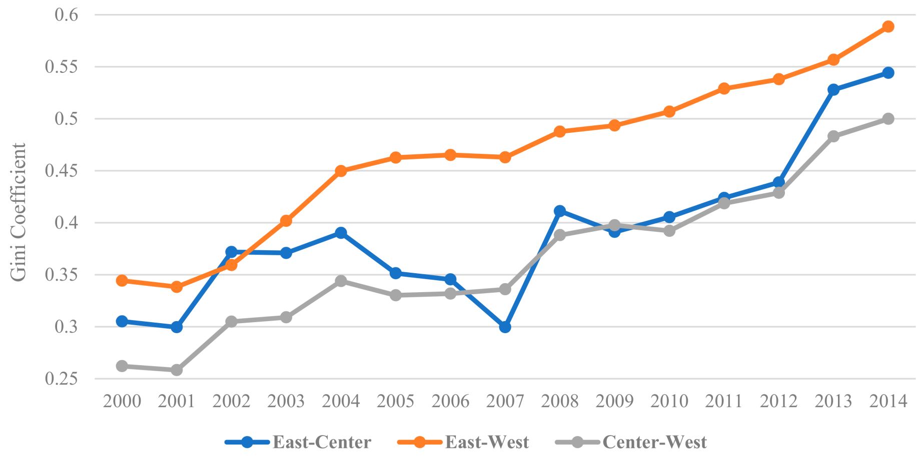

Figure 4. Trajectories of inequality of inter-regional carbon intensity Gini coefficient.

In terms of a long-term evolution, the inter-regional carbon intensity Gini coefficient between Eastern China and Central China, Eastern China and Western China, and Central China and Western China follow similar tendencies. Their inter-regional carbon intensity Gini coefficients increased from 2000 to 2014. However, the inter-regional carbon intensity Gini coefficient in Eastern China and Central China decreased from 2004 to 2007. The annual average growth rate of the inter-regional carbon intensity Gini coefficient between Central China and Western China was highest, followed by Eastern China and Central China, and by Eastern China and Central China. The compound annual growth rate of the inter-regional carbon intensity Gini coefficients between Eastern China and West China, Eastern China and Central China, and Eastern China and Central China were 4.72%, 4.22% and 3.90% per year, respectively.

The gap of inter-regional carbon emission is significantly increasing; the industry transfer has caused this phenomenon [74]. Similarly, scholars have generally agreed that the inter-regional industry transfer from East to West and Center resulted the pollution and carbon leakage phenomenon [1,2] mainly due to the industry transfer focused on the high carbon and high energy consuming industries and related manufacturing [3]. Industry transfer is not the root of the transfer of carbon pollution, however, more accurately the high-carbon industry transfers leads to pollution transfer. Especially after 2008, the gap of inter-regional carbon emission is more obvious, that is because the coastal industry accelerated the industry transfer after the financial crisis in 2008.

From the specific industry transfer and carbon transfer, the industry transfers from the East to West and Center are focused on the high-carbon industry, for example mining industry, chemical industry, electric coal water production and supply industry, non-metallic mineral products industry, metal smelting, and products industry. Especially the production and supply of electric coal water supply industries, with a small amount of industry transfer contributing to a larger amount of carbon transfer. The Central and Western regions are the net rolled in industry transfer areas, the Eastern coast of the net rolled out transfer area, the southern coast regions show the performance of the transfer of consumption, export transfer, while the Central and Western regions show the performance of consumption exit, export exit into. From the view of inter-regional carbon transfer, the carbon intensity of the regional industry in China shows the East as being highest, followed by the Center and West. Therefore, the spatial trend of carbon transfer is basically similar with the trend of industry transfer.

4.3. Drivers for Inequality of the Carbon Intensity Gini Coefficient

Figure 5 displays the drivers of inequality of the carbon intensity Gini coefficient. As shown in Figure 5, trans-variation intensity was the leading contributor for the increasing national-scale carbon intensity Gini coefficient. It was followed by the inter-regional carbon intensity Gini coefficient, which was always higher than that of the intra-regional and inter-regional carbon intensity Gini coefficients. It should be noted that the inter-regional carbon intensity Gini coefficient offset the increase in national-level carbon intensity Gini coefficient between 2000 and 20003. In 2014, the contributing rate of transvariation intensity to national-level carbon intensity Gini coefficient was 71.71%, whereas the contributing rates of intra-regional and inter-regional carbon intensity Gini coefficient were 24.82% and 3.47%, respectively.

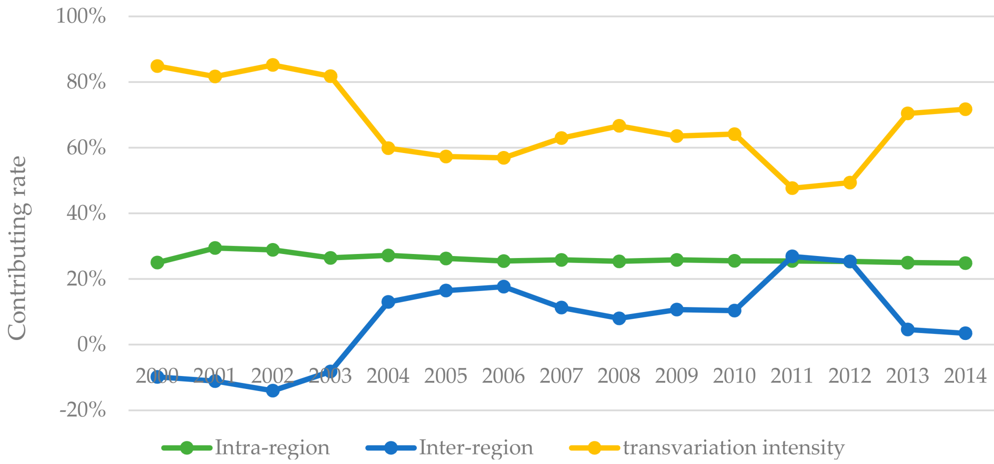

Figure 5. Contributing rates to national-scale carbon intensity Gini efficient.

5. Conclusions and Policy Implications

5.1. Conclusions

With the use of the Gini coefficient and its subgroup decomposition method, we investigated the inequality of carbon intensity in Chin from 1995 to 2013. The main conclusions are listed below:

1. At a national level, the inequality of carbon intensity Gini coefficient is rising throughout China. In particular, the growth rates of carbon intensity coefficient are accelerating since 2007.
2. At an inter-regional level, long-term trends of the carbon intensity Gini coefficient in Central China and Western China increased, while they decreased in Eastern China.
3. At an intra-regional level, the carbon intensity Gini coefficient increased between Eastern China and Western China, Eastern China and Central China, and Central China and Western China.
4. The leading contributing factor for the observed increase of the national-scale carbon intensity Gini coefficient was the trans-variation intensity.

5.2. Policy Implications

The Chinese government promised that carbon dioxide emissions will reach a peak, and that carbon intensity will be reduced by 60–65% until 2030. Specific goals for each province and administrative level must be scientifically calculated in order for the country to meet this national goal. Local governments at all levels should then implement the appropriate action necessary to achieve these specific goals. Every province and administrative region must be assessed and held accountable, and accordingly, the following policy suggestions are proposed:

Due to the ever-increasing inter-provincial carbon intensity difference in China, using the same carbon reduction goal for each province is not only unscientific, but also unfair. Considering the tremendous differences, and from a perspective of policy-making costs, a uniform carbon emission reduction policy can be applied to Eastern China with its comparatively small inter-provincial differences; however, for Western and Central China with greater differences, local governments at all levels should be actively encouraged to participate in the formulation of regulations and strategies to reduce carbon emissions and participate in carbon trading. China's five major energy bases all have high carbon intensity values. To achieve China's national carbon intensity goal, it is important to improve the energy utilization efficiency of provinces with abundant energy.

In addition, China is currently promoting nationwide industrial transformation and transfer. Numerous high-carbon-emission enterprises are moving from coastal to inland areas. Different industries differ greatly in their energy consumption; however, in energy-output provinces, unsophisticated industrial structures lead to high carbon emissions. To achieve a balanced development, the more economically developed provinces should compensate for provinces that have fewer resources and energy output or an undeveloped economy, and consequently, the eastern coastal regions should compensate for the central and western regions, to promote social and economic development in these areas.

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