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Factor Decomposition Analysis of Carbon Emission of Energy Consumption

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By extending the Generalized Fisher Index Decomposition from four factors to five factors based on extending the Johan identity, we established the factor decomposition model of carbon emission per capita of energy consumption in Jilin Province that considered comprehensively the impacts of industrial energy structure, industrial energy intensity, industrial structure, economic development and population urbanization on carbon emission of energy consumption. We analyzed carbon emission of energy consumption and quantified the contribution ratio of various influencing factors during 2000-2012 based on this model. Meanwhile, we discussed the effects of various influencing factors' changes on carbon emission increase. The analysis results also provide corresponding policy recommendations about energy-saving and emission-reduction.

1. Introduction

Analyzing and studying related influence factors of carbon emissions based on energy consumption in Jilin Province, and putting forward corresponding suggestions and measures of energy-saving and emission-reduction, have important significance in prompting Jilin Province to develop Low-carbon economy.

From the literatures of some domestic and overseas scholars, such as Lise (2006), Xu et al (2006), Lin et al (2009), Zhu et al (2009), Jiang et al (2011), Tian et al (2014), and the review of 124 research papers about index decomposition analysis written by Ang et al (2000), we can learn that the factor decomposition analysis on carbon emission more use Laspeyres index and Divisia index decomposition and their improved approaches. However, both two approaches above have some defects. GFI approach proposed by Ang, et al (2004) is a compromise approach for the two above, and overcomes well the defects existing in themselves. Ang, et al (2004) compared GFI approach with five widely known index decomposition approaches, including Laspeyres index, Passche index, AMDI, LMDI Ⅰand LMDI Ⅱ. And meanwhile, the factor-reversal, time-reversal, proportionality, aggregation, zero-value robust and negative-value robust tests were used in testing the former six approaches. According to the test results, GFI only did not pass the aggregation test, while others all had two or more impassable tests. Therefore, GFI, which exhibits good properties of factor decomposition, is the optimal factor decomposition approach.

This paper first discusses the factor decomposition process of Generalized Fisher Index approach (GFI) and thereafter extends the identity of carbon emission which was presented by Albrecht Johan et al (2002). Furthermore, combined with practical situation of energy consumptions per capita in Jilin Province, we establish the factor decomposition model of carbon emission of energy consumption that can consider comprehensively the impacts of industrial energy structure, industrial energy intensity, industrial structure, economic development and population urbanization on carbon emission of energy consumption, and make an empirical analysis according to the relevant data in Jilin Province.

2. Establishment of the model

2.1 Decomposition of GFI model

In fact, GFI approach extends the traditional two-factor Fisher index decomposition approach to n-factor scheme, and its realization process is as follows.

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Let W be an aggregate indicator whose value is given by the disaggregated data of n variables or factorsX_{1ij}, X_{2ij}, …, X_{nij}. Subscript i and j denote respectively the sub-category of the aggregate: type of energy and industrial category. To analyse structure change, we can let $0, T$ denote year respectively and have:

$$W = \sum_i \sum_j X_{1ij} X_{2ij} \cdots X_{nij} \tag{1}$$

$$W^0 = \sum_i \sum_j X_{1ij}^0 X_{2ij}^0 \cdots X_{nij}^0 \tag{2}$$

$$W^T = \sum_i \sum_j X_{1ij}^T X_{2ij}^T \cdots X_{nij}^T \tag{3}$$

Define N={1,2,…,n} and the cardinality of N is n. Let Z be a subset of N where the cardinality of Z is $z^{'}$, and ∅ is a null subset. Define the functions:

$$W(Z) = \sum_i \sum_j (\prod_{l \in Z} X_l^T \prod_{m \in N \setminus Z} X_m^0) \tag{4}$$

$$W(\emptyset) = \sum_i \sum_j (\prod_{m \in N} X_m^0) \tag{5}$$

Following the “geometric average” principle, W^T/W^0 can be decomposed into n components:

$$D = \frac{W^T}{W^0} = D_{X_1} D_{X_2} \dots D_{X_n} \tag{6}$$

Where D_{X_k}(k=1, 2, …, n) is the decomposition factor item of GFI approach and the component for factor X_k(k=1, 2, …, n) is given by:

$$D_{X_k} = \prod_{\substack{Z \subset N \\ k \in Z}} [\frac{W(Z)}{W(Z \setminus \{k\})}]^{\frac{1}{n} \cdot \frac{1}{\binom{n-1}{z^{'}-1}}} = \prod_{\substack{Z \subset N \\ k \in Z}} [\frac{W(Z)}{W(Z \setminus \{k\})}]^{\frac{(z^{'}-1)!(n-z^{'})!}{n!}} \tag{7}$$

2.2 Extended Johan identity

Albrecht Johan et al(2002)put forward the identity of carbon emission:

$$C = \sum_i \frac{C_i}{E_i} \cdot \frac{E_i}{E} \cdot \frac{E}{Y} \cdot \frac{Y}{P} \cdot P \tag{8}$$

Where C, C_i, E, E_i, Y and P denotes the total amount of carbon emissions, carbon emissions of i-type energy, the total amount of energy consumption, i-type energy consumption, GDP and population respectively.
According to Johan identity, energy structure, energy intensity, economic development and population size are the main influence factors of carbon emissions. However, energy structure, energy intensity, industrial structure, economic development, population structure and population size all have been the important influence factors of carbon emissions based on extensive researches by domestic and overseas scholars. Thus, this paper extends Johan identity and its purpose is to analyze more comprehensively the main influence factors of carbon emissions per capita of energy consumption. The extended Johan identity is:

$$C = \sum_i \sum_j \frac{C_{ij}}{E_{ij}} \cdot \frac{E_{ij}}{E_j} \cdot \frac{E_j}{Y_j} \cdot \frac{Y_j}{Y} \cdot \frac{Y}{P} \cdot \frac{UP+RP}{P} \cdot P \tag{9}$$

Where the meaning of C, Y and P are the same as that of Eq (8); C_{ij} and E_{ij} represents the amount of carbon emissions and energy consumption of i-type energy of the jth industry respectively; E_j and Y_j denotes energy consumption and GDP of the jth industry separately. While population structure is reflected by dividing total population into urban population and rural population, UP and RP means severally the quantity of urban and rural population.

2.3 The factor decomposition model of carbon emissions per capita of energy consumption in Jilin Province

We propose the definitions. $F_{ij} = C_{ij}/E_{ij}$: carbon emission coefficient, that is carbon emissions of unit consumption of i-type energy; $ES_{ij} = E_{ij}/E_j$: industrial energy structure, the proportion of i-type energy consumption in total energy consumption of the jth industry; $IN_j = E_j/Y_j$: industrial energy intensity, energy consumption of unit GDP in the jth industry; $IS_j = Y_j/Y$: industrial structure, the proportion of the jth industry’s output value in GDP; $R = Y/P$: GDP per capita, which represents the economic development level; $U = UP/P$: the proportion of urban population in total population, that means the population urbanization level, while population structure is reflected by the population urbanization level. The formula of Carbon emissions per capita can be accordingly written as:

$$AV = C/P = \sum_i \sum_j F_{ij} \cdot ES_{ij} \cdot IN_j \cdot IS_j \cdot R \cdot U \tag{10}$$

By Eq (10), the factors that influencing the change of carbon emissions per capita can be decomposed to carbon emission coefficient, industrial energy structure, industrial energy intensity, industrial structure, economic development and population urbanization. Thereinto, F_{ij}, carbon emission coefficient, is fixed in general. Because of the fact of energy consumption and economic development in Jilin, types of energy include six kinds of main energy sources and industries are divided into three industries.
Let AV^T denote carbon emissions per capita of T period and AV^0 mean that of base period. According to the decomposition of GFI model, the change of carbon emissions per capita can be expressed as:

$$D = AV^T/AV^0 = D_{X_1} \cdot D_{X_2} \cdot D_{X_3} \cdot D_{X_4} \cdot D_{X_5} \tag{11}$$

Where D is carbon emissions per capita, D_{X_1}, D_{X_2} , D_{X_3}, D_{X_4} and D_{X_5} is the factor of industrial energy structure, industrial energy intensity, industrial structure, economic development and population urbanization respectively. D_{X_1}, D_{X_2}, D_{X_3}, D_{X_4} and D_{X_5} can be expressed by Eq (7) and their expressions are omitted here.

3. Empirical analysis

3.1 Data sources and calculation

The Eq of calculating carbon emissions of energy consumption in this paper is:

$$C = \sum_i E_i \cdot F_i \tag{12}$$

Where C means the total amount of carbon emissions of energy consumption, and E_i represents i-type energy consumption which is equal to standard coal, and F_i denotes carbon emission coefficient of i-type energy. The types of energy include coal, coke, crude oil, gasoline, diesel and natural gas, the carbon emission coefficients of which obtained by Zhao et al (2009) basing on the default value of IPCC carbon emission calculation guidelines (See Table 1). On the basis of Eq (12), we calculate carbon emissions per capita in previous years during 2000-2012. The data of energy consumption and population quantity all come from China Energy Statistical Yearbook and Jilin Statistical Yearbook over the years.

Table 1: Coefficient of carbon emissions of different major energy

Type of Energy	Coal	Coke	Crude Oil	Gasoline	Diesel	Natural Gas
$\boldsymbol{F_i}$	0.7559	0.8550	0.5857	0.5538	0.5921	0.4483

Unit: 10,000 tons/10,000 tons of standard coal

Other data related to the influence factors also all stem from China Energy Statistical Yearbook and Jilin Statistical Yearbook over the years. These data include the respective energy consumption of every type in three industries, the total amount of energy consumption in three industries, the output value of each in three industries, GDP, urban population quantity, et al. In the influence factors, the population urbanization level is represented by the ratio of non-agricultural population to the total population in the province and industrial structure is measured by the proportion of GDP of every industrial output value in three industries, meanwhile, the output value of each in three industries and GDP is calculated with constant price of 2000 to eliminate the effect of price change. According to the calculated influence factors data and Eq (11), the GFI decomposition calculation is made and the results can be seen in Table 2 and Table 3, where D, $\mathrm{D_{X_1}}$, $\mathrm{D_{X_2}}$, $\mathrm{D_{X_3}}$, $\mathrm{D_{X_4}}$ and $\mathrm{D_{X_5}}$ are the same as that of Eq (11).

Table 2: GFI decomposition of per capita carbon emissioergy consumption in Jilin Province during 2000-2012

year	$\mathrm{D_{X_1}}$	$\mathrm{D_{X_2}}$	$\mathrm{D_{X_3}}$	$\mathrm{D_{X_4}}$	$\mathrm{D_{X_5}}$	D
2000-2001	1.0037	0.9491	1.0179	1.0889	1.0065	1.0629
2001-2002	1.0042	0.9532	0.9997	1.0899	1.0153	1.0588
2002-2003	1.0021	1.0406	1.0228	1.0982	1.0114	1.1847
2003-2004	0.9955	0.9311	1.0268	1.1206	1.0046	1.0714
2004-2005	1.0002	1.0933	1.0217	1.1178	1.0004	1.2495
2005-2006	1.0056	0.9552	1.0226	1.1457	0.9983	1.1235
2006-2007	1.0000	0.9434	1.0376	1.1539	0.9997	1.1290
2007-2008	0.9991	0.9920	1.0241	1.1538	1.0020	1.1734
2008-2009	1.0059	0.8546	1.0090	1.1322	0.9983	0.9805
2009-2010	1.0010	0.9654	1.0597	1.1362	1.0109	1.1763
2010-2011	1.0009	1.0275	1.0184	1.1369	1.0529	1.2537
2011-2012	1.0009	0.8951	1.0055	1.1301	0.9766	0.9941
2000-2012	12.0192	11.6005	12.2659	13.5042	12.0768	13.4579

Table 3: Contribution ratio of five factors that influencing per capita carbon emissions of energy consumption in Jilin Province during 2000-2012

year	D_{X_1}	D_{X_2}	D_{X_3}	D_{X_4}	D_{X_5}
2000-2001	19.81	18.73	20.09	21.49	19.87
2001-2002	19.84	18.83	19.75	21.53	20.06
2002-2003	19.36	20.11	19.76	21.22	19.54
2003-2004	19.60	18.33	20.22	22.07	19.78
2004-2005	19.11	20.89	19.52	21.36	19.12
2005-2006	19.61	18.63	19.94	22.34	19.47
2006-2007	19.48	18.37	20.21	22.47	19.47
2007-2008	19.32	19.18	19.80	22.31	19.38
2008-2009	20.12	17.09	20.18	22.64	19.97
2009-2010	19.35	18.66	20.48	21.96	19.54
2010-2011	19.11	19.62	19.45	21.71	20.11
2011-2012	19.99	17.87	20.08	22.57	19.50
2000-2012	19.55	18.87	19.96	21.97	19.65

Unit: %.

3.2 Analysis of Influencing Factors

Based on Eq (12), we calculate that carbon emissions per capita in Jilin Province during 2000-2012 indicated a trend of continuous growth as a whole and the average growth rate per year was 8.81%. As of 2012, carbon emissions per capita reached 3.47 tons per capita and it was 2.69 times that of 2000. The growth of carbon emissions per capita was relatively slow from 2000 to 2002, its average growth rate per year was only 3.83%. The annual increase rate during 2003-2008 was the fastest and up to 12.39%, moreover, that of 2005 was more than 20%. The mean growth level of 2010-2012 was 9.31% and only slightly higher than the global average level during 2000-2012.

According to the results of GFI decomposition and contribution ratio in Table 2 and Table 3, the five factors all constituted significant effects on the change of carbon emissions per capita of energy consumption in Jilin. Wherein, industrial energy intensity was the inhibitory factor and others were the pulling factors. In comparison, the contribution degree of economic development was the highest and it was 13.5042, accounting for 21.97%. Those of industrial structure, population urbanization and industrial energy structure took second places and was 12.2659, 12.0768, 12.0192 respectively, accounting for 19.96%, 19.65%, 19.55% separately. That of industrial energy intensity was 11.6005, which occupied the minimum, accounting for 18.87%.

The contribution ratio of economic development always stayed from 21.2% to 22.7% during the whole 2000-2012. The mean increase rate per year of GDP per capita with constant price of 2000 in Jilin Province was 12.8%, and compared with GDP per capita of 2000, that of 2012 was increased by 3.23 times. Generally energy consumption was a main basic input in the industrialization process of developing countries and carbon emission was one of the direct products of energy consumption. Therefore, rapid economic development of this period in Jilin Province, as a region in a developing country, had certain pull effect on the increase of carbon emissions per capita.

Industrial structure has significant positive effect on the increase of carbon emissions per capita and its average contribution ratio was 19.96%. The output value of secondary industry accounted for maximum weight from 2003 all long and its share of GDP rose from 39.40% of 2000 to 53.41% of 2012, where primary industry proportion of GDP decreased from 20.43% to 11.83% and tertiary industry proportion dropped from 40.17% to 34.76% in the same period. Secondary industry share of carbon emissions rose from 86.48% of 2000 to 90.77% of 2012 and always occupied the absolute dominant position, whereas primary industry proportion declined from 1.63% to 0.73% and tertiary industry proportion fell by 1.64% too. Carbon emissions of secondary industry, which occupying more than half of GDP and charactered by low additional value and heavy energy waste, grew continuously and steadily in long run, meanwhile, the output value share of low energy waste primary and tertiary industry continually decreased correspondingly. Accordingly, the general change of industrial structure manifested as significant positive effect on the increase of carbon emissions.

The mean contribution ratio of population urbanization was 19.65% and the ratio of non-agricultural population to the total population in the province in 2012 was 46.89%, which was 1.08 times of that in 2000. Population urbanization measures the ratio of population that engaging in production and life in cities and towns and the demand for energy consumption of urban population's production and life style is much higher than that of rural population. Therefore, the increase of population urbanization proportion will inevitably result in the increase of energy consumption and carbon emissions. From the change of urbanization population data, the growth range of urbanization population was not obvious during the whole period. So the urbanization process in Jilin Province pulled the increase of carbon emissions to some extent, but not very seriously.

The average contribution ratio of industrial energy structure change was lower than that of population urbanization only by 0.1%. Table 1 indicates coke has the highest carbon emission coefficient, coal's is the second high and natural gas's is the lowest. Based on calculation, carbon emission proportion of coal consumption played a dominant role in the carbon emissions of main energy consumption during 2000-2012 and its all industry average proportion reached 71.81%, crude oil and coke occupied the second and third place separately, where the sum of carbon emission proportions of other energy consumption was less than 10%. Among them, coal, which had the second high carbon emission coefficient and the highest carbon emission proportion, still rose annually by 0.99%. Coke, which had the highest carbon emission coefficient and the carbon emission proportion was 5.60%, had the average growth rate per year of 3.32%. Crude Oil reduced annually by 5.63%, but its carbon emission coefficient and carbon emission proportion were significantly lower than coal. Carbon emission proportions of other types of energy had not change in general. Hence, the industrial energy structure change should have positive effect on the increase of carbon emission. From the industrial decomposition of energy structure of carbon emission, in the secondary industry that occupied the absolute predominance of carbon emission scale, carbon emission proportion of coal consumption was 74.05% and that of crude oil and coke was 16.04% and 6.34% respectively, and the sum of other types of energy consumption carbon emission proportions didn't reach 5%. Thereinto, the cumulative proportion of carbon emission of coal annually rose 1.36%, which of coke grew 2.81% a year on average, and which of crude oil was reduced by 5.99%. Accordingly, the overall change of energy consumption structure in the secondary industry should have pulling effect on the increase of carbon emission. As the proportion of the primary and tertiary industry in carbon emission industrial structure was relatively smaller, the effect of that on the change of carbon emission was not obvious. Consequently, the general change of energy consumption structure and industrial energy consumption structure presented stimulating effect on the increase of carbon emission.

Industrial energy intensity represented negative effect on the change of carbon emissions per capita and its average contribution ratio was 18.87%. The energy intensity of all industry average and each industry all had declined during the period of 2000-2012, these illustrated that industrial energy efficiency in Jilin Province was increasing year by year. Among them, energy intensity of all industry average dropped by 3.50% a year on average, that of primary industry decreased most significantly and its average rate of decline per year was 7.17%, and that of secondary and tertiary industry was 3.23% and 4.12% separately. In general, energy intensity or energy efficiency is closely linked with the factors such as technology progress, energy structure, industrial structure, etc. Based on the above analysis, however, the change of energy structure and industrial structure has positive effect on the increase of carbon emissions in Jilin Province during 2000-2012. Therefore, the decline of energy intensity was mainly caused by technology progress and to some extent it inhibited the increase of carbon emission of energy consumption in Jilin Province during this period.

4. Conclusions and recommendations

Related influencing factors of carbon emission can be more refined by the factor decomposition model of carbon emission per capita of energy consumption in Jilin Province. The results of empirical analysis indicate that economic development has the highest contribution to carbon emission per capita change of energy consumption. Industrial structure, population urbanization and industrial energy structure take the second places and industrial energy intensity has the lowest contribution. Among them, economic development, industrial structure, population urbanization and industrial energy structure have remarkable pulling effects on the increase of carbon emissions per capita, and industrial energy intensity is an inhibitory factor. As economic development is the inventible choice of developing countries and regions, we can provide scientific reference of decision-making for carbon emission reduction from the following aspects.

Firstly, Jilin Province should promote resources integration, upgrading and updating of products in the secondary industry fields to reduce production and export of resource intensive products on the one hand, and on the other hand, can strive to develop the tertiary industry with high added value and low energy consumption characteristics, and improve continuously its proportion in the total economy.

Secondly, the investment in education and the strength in conduct propaganda should be increased in order to raise the comprehensive quality and the environmental awareness of urban population, form gradually the production and living consumption style of energy saving, reduce the pulling effect that population urbanization influences in itself the increase of carbon emission.

Thirdly, Jilin Province can promote designedly the exploitation and utilization of renewable energies and try to maintain the sustained growth of those, the renewable energies include nuclear electricity, hydroelectricity, wind power, solar power, geothermal energy, biomass energy, etc.

Fourthly, Jilin Province should strengthen the investment of advanced energy-saving technology, encourage and urge heavy energy-consumption enterprises to use more advanced production process and technology and renew laggard technology and equipment, reinforce supervision and management on energy consumption of various industries and enterprises, in order to improve energy utilization efficiency of heavy energy-consumption industries and enterprises as well as achieve energy-saving and emission-reduction.

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