sustainability

MDPI

Article

Effect of Population Structure Change on Carbon Emission in China

Wen Guo [1,2,*], Tao Sun [2] and Hongjun Dai [2,3]

1 Accounting Department, College of Accounting, Nanjing University of Finance & Economics, Nanjing 210046, China
2 College of Economics and Management, Research Institute of Financial Development, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China; suntao@nuaa.edu.cn (T.S.); dhj@hnnu.edu.cn (H.D.)
3 College of Economics and Management, Huainan Normal University, Huainan 232038, China
* Correspondence: xsyjgw@nuaa.edu.cn; Tel.: +86-25-8489-3060 (ext. 925)

Academic Editors: Malin Song and Seunghwan Myeong
Received: 25 October 2015; Accepted: 17 February 2016; Published: 4 March 2016

Abstract: This paper expanded the Logarithmic Mean Divisia Index (LMDI) model through the introduction of urbanization, residents' consumption, and other factors, and decomposed carbon emission changes in China into carbon emission factor effect, energy intensity effect, consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect, and then explored contribution rates and action mechanisms of the above six factors on change in carbon emissions in China. Then, the effect of population structure change on carbon emission was analyzed by taking 2003–2012 as a sample period, and combining this with the panel data of 30 provinces in China. Results showed that in 2003–2012, total carbon emission increased by 4.2117 billion tons in China. The consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect promoted the increase in carbon emissions, and their contribution ratios were 27.44%, 12.700%, 74.96%, and 5.90%, respectively. However, the influence of carbon emission factor effect (−2.54%) and energy intensity effect (−18.46%) on carbon emissions were negative. Population urbanization has become the main population factor which affects carbon emission in China. The "Eastern aggregation" phenomenon caused the population scale effect in the eastern area to be significantly higher than in the central and western regions, but the contribution rate of its energy intensity effect (−11.10 million tons) was significantly smaller than in the central (−21.61 million tons) and western regions (−13.29 million tons), and the carbon emission factor effect in the central area (−3.33 million tons) was significantly higher than that in the eastern (−2.00 million tons) and western regions (−1.08 million tons). During the sample period, the change in population age structure, population education structure, and population occupation structure relieved growth of carbon emissions in China, but the effects of change of population, urban and rural structure, regional economic level, and population size generated increases in carbon emissions. Finally, the change of population sex structure had no significant influence on changes in carbon emissions.

Keywords: population structure; carbon emission; LMDI; urbanization; residents' consumption

1. Introduction

With the intensified change in the global climate, the problem of carbon emissions from burning fossil energy has become an important focus. The fourth assessment report of IPCC pointed out that human factors were the main reasons causing a dramatic increase of global carbon emission; therefore, the effect of expansion of the population scale and change in demographic structure has become an essential academic issue. Due to historical reasons, the one-child policy led to the current special population structure in China, and also provided typical sample data for research into the effect of change of demographic structure on carbon emission. The change of Chinese demographic structure (including population age structure, population sex structure, population education structure, population urban and rural structure and population occupation structure) is shown in Figure 1.

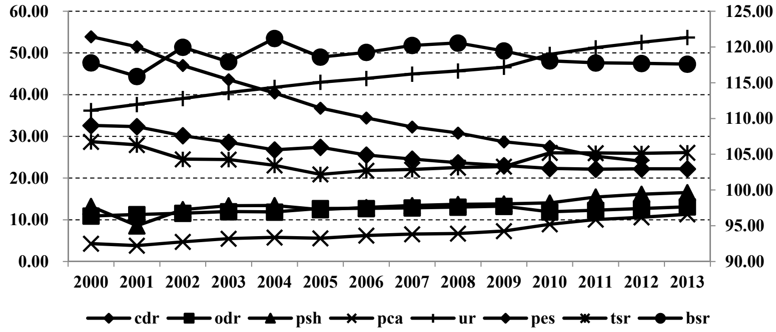

Figure 1. Change of Chinese population structure from 2000 to 2013. Data source: (1) Data of children dependency ratio (cdr), elderly dependency ratio (odr), proportion of the population in senior high school (psh), proportion of the population in college and above (pca), ratio of population urbanization (ur), sex ratio of total population (tsr), and sex ratio at birth (bsr) were collected from *China Statistical Yearbook* [1] for 2001–2014, while data of children dependency ratio and elderly dependency ratio in 2000–2001 were obtained from China Commonly Used Population Data Set Since 1990 [2]. (2) Data of the proportion of employees in state-owned units in total China urban employment (pes) were from the *China Labour Statistical Yearbook* [3] in 2001–2013.

At present, there are significant features regarding aspects of age structure, urban and rural structure, education structure, sex structure, and occupational structure in the Chinese population. Firstly, China began to carry out the one-child policy in the 1970s, which was officially designated as the basic national policy in 1982. This policy caused low birth rates over a long period. In addition, improved living standards, advances in medical technology, and other factors also caused a rapid decline in the death rate. The phenomenon of low birth rates and low death rates led to the main features of age structure in China as being "declining birthrates" and "aging populations". According to Figure 1, it was found that the child dependency ratio and the elderly dependency ratio continuously increased since 2010, and met the above characteristic of the population age structure. Secondly, China has entered a rapid development stage of population urbanization since the 1980s. In 2000–2013, the population urbanization ratio in China increased from 36.22% to 53.73% (see Figure 1), and maintained an average annual growth rate of more than 1%. Wang [4] indicated that population urbanization in China is still in the middle stage, and exhibits disparity with the world's average level. We can expect that Chinese population urban and rural structure will change with the rapid development of population urbanization in China in the future. Thirdly, Figure 1 showed that the Chinese population education structure also changed greatly since the new century, the proportion of the population of senior high school and proportion of the population in college and above, respectively, rose from 13.20% and 4.28% to 16.52% and 11.32% in 2000–2013, indicating the increase of population quality in China. Fourthly, Chinese population sex structure was in long-term imbalance due to the child-bearing viewpoint of "preference for sons over daughters". Figure 1 also showed that the Chinese total population sex ratio has been about 105 since 2000, significantly higher than the normal level. On the other hand, the sex ratio at birth in China was higher than 115 in 2000–2013; the cumulative effect will undoubtedly lead to more serious population gender imbalances in the future. Finally, due to historical reasons, the state-owned economic component played an important role in the Chinese economy, with the depth of market economic reform, and the proportion of the state-owned economy gradually reducing. The proportion of employees in state-owned units in total Chinese urban employment rapidly declined in recent years (see Figure 1), which confirmed changes of population occupational structure in China.

Regarding the effect of population structure change on carbon emission, the conclusions of scholars are varied. Liddle [5] found that the effect of population age structure on carbon emission from transport energy consumption presented a change tendency as an inverted "U" type, while Okada [6], and Menz *et al.* [7] believed that aging populations would reduce the overall carbon emission from energy consumption. Zhu *et al.* [8], Knight *et al.* [9], and many other scholars found that the level of urbanization significantly affected overall carbon emission. Katircioğlu [10] took energy consumption in Turkey as a case; his study showed that the development of high education level and improvement of population quality will promote growth of the power consumption and the petroleum consumption regardless of long term or short term timeframes. Obviously, population structure change significantly affected change of carbon emission; therefore, this paper examined change of carbon emission of 31 provinces in China during 2003–2012 as the research object, focusing on the analysis of the effect of China's population structure change on carbon emission from the perspectives of development of urbanization and residents' consumption, and attempted to explain the pattern of change in carbon emission in China from the perspective of population structure change.

The following content of this paper was organized as follows. In Section 2, we summarize the literature about this issue. Section 3 discusses the model, methodology, and the data which was used in this paper. Results were calculated and empirical results are summarized in Sections 4 and 5 respectively. Finally, Section 6 concludes this paper.

2. Literature Review

At present, structural decomposition analysis (SDA) and index decomposition method (IDA) are the two main decomposition methods to analyze carbon emission. Although the two methods are widely applied [11,12], Hoekstra *et al.* [13], and Ang [14] believed that the IDA method adapts to the empirical analysis at all levels as macro, regional, and industry based on a comparison of the above two methods. The IDA method also has advantage in data acquisition; therefore, it was more popular in academic study. The IDA method can be further subdivided into two types as the Laspeyres Index Decomposition Method and the Divisia Index Decomposition Method. Ang *et al.* [15] found that the Logarithmic Mean Divisia Index (LMDI) decomposition method has advantages of handling null, independent data paths compared with the Laspeyres Index Decomposition Method, and it was more applicable to empirical research. Therefore, the application of the LMDI method in the field of carbon emission measurement and decomposition was more extensive in recent years [16,17]. Many scholars also put forward many corresponding improved forms of LMDI on the basis of specific study objects [18–20].

Regarding the relationship between carbon emission and demographic factors, the early studies mostly focus on the influence of population scale on carbon emission. Rosa *et al.* [21] collected the cross-sectional data and found that the population elasticity was close to 1. O'Neill *et al.* [22] also believed that the impact of population on carbon emission was only manifested by the scale effect, while controlling other influencing factors, with elasticity close to 1. Ping [23] also obtained a similar conclusion. However, Satterthwaite [24] found that the growth of population scale could promote the growth of carbon emission, while the contribution of consumption level and consumption scale, which grows with the growth of population scale, on promoting the growth of carbon emission was greater. Yao *et al.* [25], and Wang *et al.* [26] took time-series data at the national level in China as a sample; their studies found that growth of consumption scale and rising consumption levels were important factors influencing the growth of carbon emission.

In recent years, the influence of population structure change on carbon emission has drawn more and more attention. Firstly, change of population age structure (aging populations) is a kind of typical population structure change, and has significant impact on change of carbon emission. York [27] believed that population size and age structure affected carbon emission significantly through affecting total energy consumption. Liddle *et al.* [28] analyzed the effect of two age groups, 20–34 and 35–60, on carbon emission. The results showed that elasticity of carbon emissions in the two samples were contradictory; elasticity of the former group is positive, but the other is negative. Lugauer *et al.* [29] found that carbon emission increased rapidly with the increasing of the proportion of the population aged 35 to 49. Liddle [5] analyzed the impact of age structure on carbon emission from residents' electricity consumption and transportation energy consumption. He believed that the impact of age structure on carbon emission from transportation energy consumption appeared as an inverted "U" type; namely, the influence coefficients of the minimum and maximum age groups were negative, and the influence coefficient of the age group of 20–34 is positive, while the influence direction of age structure on carbon emission from residents' electricity consumption was the inverse. Zagheni [30] argued that total carbon emission would decrease with the growth of the proportion of the population over the age of 60; namely, an increase of elderly population could reduce carbon emission, and the conclusion of the study of Okada [6], Menz *et al.* [7] was similar. In addition, Laureti *et al.* [31] took attention of the effect of population structure on nitrogen oxides; this study also supports the above view's conclusion.

Secondly, many scholars studied the impact of population urban and rural structure change (urbanization) on carbon emission, and there were two methods of research for this topic. The first assumed that there was a single causal relationship from urbanization to carbon emission, to explore the influence of urbanization on carbon emission. However, due to differences between their study samples and other factors, they did not reach the same conclusion. Jorgenson [32] took OECD countries as samples and found that the effect of urbanization on carbon emission in the national level was not significant, Liddle *et al.* [28] and Jorgenson [33] obtained a similar conclusion. Jorgenson *et al.* [34,35] found that urbanization had a significant effect on carbon emission, while its effect coefficient is small based on a mixed sample with data of developed countries and developing countries. Studies by Poumanyvong *et al.* [36], Martinez *et al.* [37], Poumanyvong *et al.* [38], Zhu *et al.* [8], and Knight *et al.* [9] supported the above conclusion. Fang *et al.* [39] argued that urbanization did not have a significant effect on carbon emission in low-income countries, but it was able to significantly reduce carbon emission in high-income countries. The second tested the two-way causality relationship between urbanization and carbon emission. Mishra *et al.* [40] found that urbanization was a one-way Grainger reason to change carbon emission in Pacific island countries in the short-term. Hossain [41] believed that there was no causal relationship between urbanization and carbon emission in newly-industrialized countries in the short-term. Al-mulali [42] verified the two-way and long-term positive causal relationship between urbanization and carbon emission in the Middle East and North African countries.

Although some literature considered the effect of population scale change, population structure change, and change of population age structure on carbon emission [43,44], most literature still ignored the effect of population sex structure change and population education and occupation structure change mentioned previously. In addition, although the positive effect of increasing the size and level of consumption on carbon emission has become a consensus, there were few studies related to the effect of change of consumption structure on carbon emission. Finally, the early one-child policy caused China to face the transformation period of population structure change, as mentioned previously; population age structure, population sex structure, population education structure, population urban and rural structure, and population occupation structure significantly changed from 1997 to 2013, and it provided a typical sample for this study. Therefore, we attempted to expand the study of this topic via the following two aspects: (1) introducing factors of demographic urbanization and residents' consumption into Kaya identity, and decomposed change of carbon emission into six effects as carbon emission factor effect, energy intensity effect, consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect through using LMDI method; their contribution rate and action mechanism on change of carbon emission was then discussed; and (2) empirically analyzed effects of regional population structure change on carbon emission and its decomposition effects by using panel data of 29 provinces in China from 2003 to 2012.

3. Methodology and Data

3.1. LMDI Decomposed Method

According to Kaya identity, the relationship between population, energy, economic, and carbon emission can be expressed as Equation (1):

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times P \quad (1)$$

where C, E, G, and P express total carbon emission, total energy consumption, GDP, and total population, respectively. We attempted to analyze the effect of population structure change on carbon emission from the perspectives of urbanization and residents' consumption based on Kaya identity, and used RC to express residents' consumption, and Equation (1) can be further extended as:

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{RC} \times \frac{RC}{P} \times P \quad (2)$$

In addition, P_u and P_r were used to express total population, RC_u^b, RC_r^b to express basic living consumption of urban and rural residents, including five classes as consumption of food, clothing, housing, household appliances and services, transportation, and communication, RC_u^{ib}, RC_r^{ib} to express non-basic living consumption, including three categories: health care, education and entertainment products and services, and other goods and services. Then, residents' consumption RC can be converted as:

$$RC = \begin{bmatrix} \frac{RC_u^b}{P_u} & \frac{RC_u^{ib}}{P_u} & \frac{RC_r^b}{P_r} & \frac{RC_r^{ib}}{P_r} \end{bmatrix} \times \begin{bmatrix} \frac{P_u}{P} & \frac{P_u}{P} & \frac{P_r}{P} & \frac{P_r}{P} \end{bmatrix}^T \times P \quad (3)$$

We can deduce the expanded Kaya equation which is based on perspectives of urbanization and residents' consumption through substituting Equation (3) above into Equation (2):

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{RC} \times \begin{bmatrix} \frac{RC_u^b}{P_u} & \frac{RC_u^{ib}}{P_u} & \frac{RC_r^b}{P_r} & \frac{RC_r^{ib}}{P_r} \end{bmatrix} \times \begin{bmatrix} \frac{P_u}{P} & \frac{P_u}{P} & \frac{P_r}{P} & \frac{P_r}{P} \end{bmatrix}^T \times P \quad (4)$$

Assumed: $ci = \frac{C}{E}$ expresses carbon emission per unit of energy, namely carbon emission factor, $ei = \frac{E}{G}$ expresses energy consumption per unit of GDP, namely energy intensity, $cif = \frac{G}{RC}$ expresses the inverse of residents' consumption ratio, namely consumption inhibitory factor, $rc_u^b = \frac{RC_u^b}{P_u}, rc_u^{ib} = \frac{RC_u^{ib}}{P_u}, rc_r^b = \frac{RC_r^b}{P_r}, rc_r^{ib} = \frac{RC_r^{ib}}{P_r}$ expresses basic and non-basic living consumption per urban resident, basic and non-basic living consumption per rural resident, respectively. $p_u = \frac{P_u}{P}, p_r = \frac{P_r}{P}$ expresses the proportions of the urban and rural population, respectively. Then, Equation (4) can be translated to Equation (5):

$$C = ci \times ei \times cif \times \begin{bmatrix} rc_u^b & rc_u^{ib} & rc_r^b & rc_r^{ib} \end{bmatrix} \times [p_u \quad p_u \quad p_r \quad p_r]^T \times P \quad (5)$$

We can deduce Equation (6) through using the log and differential to Equation (5):

$$d\ \ln C = d\ \ln ci + d\ \ln ei + d\ \ln cif + \frac{d\left(rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r\right)}{rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r} + d\ \ln P \quad (6)$$

Assumed: $s_u^b = \frac{rc_u^b p_u}{rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r}$ expresses the proportion of basic living consumption in urban residents' total living consumption, $s_u^{ib} = \frac{rc_u^{ib} p_u}{rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r}$ expresses the proportion of non-basic living consumption in urban residents' total living consumption, $s_r^b = \frac{rc_r^b p_r}{rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r}$ expresses the proportion of basic living consumption in rural residents' total living consumption, $s_u^{ib} = \frac{rc_u^{ib} p_u}{rc_u^b p_u + rc_u^{ib} p_u + rc_r^b p_r + rc_r^{ib} p_r}$ expresses the proportion of non-basic living consumption in rural residents' total living consumption. We can deduce Equation (7) as:

$$d\,\mathrm{ln}C = d\,\mathrm{ln}\left(ci \times ei \times cif \times {p_u}^{s_u^b} \times {p_u}^{s_u^{ib}} \times {p_r}^{s_r^b} \times {p_r}^{s_r^{ib}} \times \left(rc_u^b\right)^{s_u^b} \times \left(rc_u^{id}\right)^{s_u^{ib}} \times \left(rc_r^b\right)^{s_r^b} \times \left(rc_r^{ib}\right)^{s_r^{ib}} \times P\right) \tag{7}$$

Equation (7) can be translated to Equation (8); Equation (8) is the multiplicative form of carbon emission based on factor decomposition:

$$C = ci \times ei \times cif \times {p_u}^{s_u^b} \times {p_u}^{s_u^{ib}} \times {p_r}^{s_r^b} \times {p_r}^{s_r^{ib}} \times \left(rc_u^b\right)^{s_u^b} \times \left(rc_u^{ib}\right)^{s_u^{ib}} \times \left(rc_r^b\right)^{s_r^b} \times \left(rc_r^{ib}\right)^{s_r^{ib}} \times P \tag{8}$$

In order to measure the contribution value of carbon emission factor and other variables on carbon emission, we should decompose change of carbon emission into the sum or product of the above variables. This paper adopted the LMDI plus decomposition method to solve the above problem which was referred to by Ang [14]. The total effect of change of carbon emission (ΔC) from period 0 to period T can be decomposed into six effects as carbon emission factor effect (ΔC_{ci}), energy intensity effect (ΔC_{ei}), consumption inhibitory factor effect (ΔC_{cif}), urbanization effect (ΔC_{u-r}), residents' consumption effect (ΔC_{b-ib}), and population scale effect (ΔC_P). Their calculation formulas are as follows:

$$\Delta C_{ci} = L\left(C^T, C^0\right) \times \mathrm{ln}\frac{ci^T}{ci^0} \tag{9}$$

$$\Delta C_{ei} = L\left(C^T, C^0\right) \times \mathrm{ln}\frac{ei^T}{ei^0} \tag{10}$$

$$\Delta C_{cif} = L\left(C^T, C^0\right) \times \mathrm{ln}\frac{cif^T}{cif^0} \tag{11}$$

$$\Delta C_{u-r} = L\left(C^T, C^0\right) \times \left\{\left[\left({s_u^b}^T + {s_u^{ib}}^T\right)\mathrm{ln}{p_u}^T - \left({s_u^b}^0 + {s_u^{ib}}^0\right)\mathrm{ln}{p_u}^0\right] + \left[\left({s_r^b}^T + {s_r^{ib}}^T\right)\mathrm{ln}{p_r}^T - \left({s_r^b}^0 + {s_r^{ib}}^0\right)\mathrm{ln}{p_r}^0\right]\right\} \tag{12}$$

$$\Delta C_{b-ib} = L\left(C^T, C^0\right) \times \left\{\left[{s_u^b}^T\mathrm{ln}{rc_u^b}^T + {s_r^b}^T\mathrm{ln}{rc_r^b}^T - {s_u^b}^0\mathrm{ln}{rc_u^b}^0 - {s_r^b}^0\mathrm{ln}{rc_r^b}^0\right] + \left[{s_u^{ib}}^T\mathrm{ln}{rc_u^{ib}}^T + {s_r^{ib}}^T\mathrm{ln}{rc_r^{ib}}^T - {s_u^{ib}}^0\mathrm{ln}{rc_u^{ib}}^0 - {s_r^{ib}}^0\mathrm{ln}{rc_r^{ib}}^0\right]\right\} \tag{13}$$

$$\Delta C_P = L\left(C^T, C^0\right) \times \mathrm{ln}\frac{P^T}{P^0} \tag{14}$$

$$\Delta C = \Delta C_{ci} + \Delta C_{ei} + \Delta C_{cif} + \Delta C_{u-r} + \Delta C_{b-ib} + \Delta C_P \tag{15}$$

where:

$$L\left(C^T, C^0\right) = \begin{cases} \left(C^T - C^0\right) / \left(\mathrm{ln}C^T - \mathrm{ln}C^0\right), C^T \neq C^0 \\ C^0, C^T = C^0 \\ 0, C^T = C^0 = 0 \end{cases} \tag{16}$$

3.2. Variables and Data

Our work focused on regional carbon emission and its decomposition effects of 31 provinces in China from 2003 to 2012. Due to the lack of data for Tibet, we took panel data of the other 30 provinces as the sample. We selected variables and collected data from two routes. Firstly, in the study of calculation and decomposition of regional carbon emission, we used 20 kinds of terminal energy consumption in various regions and a CO_2 emission coefficient to determine regional total carbon emissions (C); this method can overcome the defect of unjust allocations in regions compared with using the three kinds of primary energy. The above 20 kinds of terminal energy consumption in various regions was shown in *China Energy Statistical Yearbook* [45] to express regional total energy consumption, and was converted into standard coal equivalent. Data of regional total GDP (G), regional total residents' consumption (RC), regional total population (P), the proportion of urban population (p_u) and rural population (p_R) were from the *China Statistical Yearbook* [1]. The used proportion of consumption on food, clothing, housing, household appliances and services, transportation, and communication of per person in residents' per capita total consumption to express the proportion of basic living consumption of rural residents (s_r^{ib}) data was also from *China Statistical Yearbook* [1], and the proportion of non-basic living consumption of rural residents (s_r^b) can be calculated by $1 - s_r^{ib}$. The calculation of these two items of data for urban residents is the same for rural residents. Secondly, the empirical study used the children dependency ratio (*children*) and the elderly people dependency ratio (*elderly*) to refer to regional population age structure, used the sex ratio of total population (*sex*) to refer to regional population sex structure, and used proportion of the population of senior high school (*senior*) and proportion of the population in college and above (*college*) to refer to the regional population education structure. The data for the above variables are from the *China Statistical Yearbook* [1]. The used proportion of employees in state-owned units in total Chinese urban employment (*occupation*) refers to regional population occupation structure, its data is from the *China Labour Statistical Yearbook* [3], and used the proportion of urban population to refer to population of urban and rural (*urban*) structure. In addition, regional total GDP (*GDP*), regional total population (*population*) were selected as control variables. After the collection, sorting, and screening of the data, its descriptive statistical results were shown in Table 1.

Table 1. Descriptive statistic results of the variables.

Variables	Unit	Max	Min	Mean	Standard Deviation
C	ten thousand tons	61,360.5100	1257.0579	17,153.4307	11,620.5029
E	ten thousand tce	27,650.3057	618.6491	7503.2948	5020.2217
G (*GDP*)	hundred million RMB	44,217.1630	390.2000	8827.2409	7853.7926
RC	hundred million RMB	14,386.5689	161.7782	2572.7959	2111.0474
p_u	%	89.3000	21.0472	48.4049	14.7594
p_r	%	78.9528	10.7000	51.5951	14.7594
s_u^b	%	72.3332	35.2805	54.9927	6.8414
s_u^{ib}	%	28.0889	9.8375	16.9141	3.3583
s_r^b	%	43.3378	4.0469	22.8320	7.9634
s_r^{ib}	%	9.9767	0.8790	5.2612	1.7912
P (*population*)	ten thousand persons	10,594.0000	534.0000	4363.0800	2631.6981
children	%	44.6500	9.6400	24.6453	7.3184
elderly	%	21.8800	7.4400	12.2259	2.3825
sex	Male/Female	115.2300	94.9200	103.9320	3.4372
senior	%	29.0483	4.8842	14.3981	4.0935
college	%	37.3503	1.8284	8.4561	5.5171
occupation	%	62.9000	11.5000	36.1880	11.6511
urban	%	89.3000	21.0472	48.4049	14.7594

Data sources: the author sorted and obtained data through collecting initial data from the *China Statistical Yearbook* [1] in 2004–2013, *China Energy Statistical Yearbook* [45] in 2004–2013, and the *China Labour Statistical Yearbook* [3] in 2004–2013. Data of regional GDP and regional total residents' consumption was adjusted by taking 2003 as the base period.

4. Decomposed Results and Discussion

According to the above statistical results, these were combined with the decomposed method and Equations (9)–(16) to calculate change of carbon emission in China from 2003 to 2012. The calculated results were shown in Figure 2.

According to Figure 2, it was found that total carbon emission (*tce*) in China increased by 4.2117 billion tons from 2003 to 2012. Consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect, which related factors of population and residents' consumption, promoted the increasing of carbon emission in China. The influence of residents' consumption effect (*rce*) is the largest among them, followed by consumption inhibitory factor effect (*cife*). These led carbon emissions to rise by 3.7222 and 1.1595 billion tons during the sample period, respectively. Urbanization effect (*ue*) and population scale effect (*pce*) drove carbon emission increases of 0.5842 and 0.2985 billion tons, respectively. However, the impact of carbon emission factor effect and energy intensity effect on carbon emission was negative in 2003–2012. The influence of energy intensity effect (*eie*) was more obvious, and it caused carbon emission reduction of 1.4161 billion tons from 2003 to 2012, while the contribution value of the carbon emission factor effect (*cefe*) was only −0.1366 billion tons. Wang [4] believed that the carbon emission factor and energy intensity embodied a technical level of energy utilization to some degree. Therefore, the above result showed that energy utilization technology was improved during the sample period in China, and reached the effect of "emission reduction by technology". However, overall carbon emission in China was increasing due to the influence of a series of external variables as total consumption of residents, population scale and urbanization, and so on.

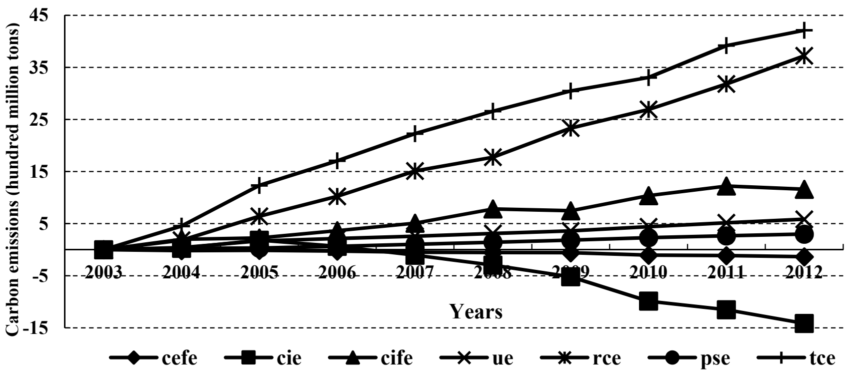

Figure 2. Decomposed results of total carbon emission in China from 2003 to 2012.

Figure 3 showed the mean contribution ratio of each decomposed effect of carbon emission. During 2003 to 2012, the contribution ratio of residents' consumption effect was 74.96% and it was the largest factor, followed by consumption inhibitory factor effect and energy intensity effect—their contribution ratios were 27.44% and −18.46%, respectively—and the contribution ratios of the urbanization effect, population scale effect, and carbon emission factor effect were 12.70%, 5.90%, and −2.54%. Residents' consumption effect and consumption inhibitory factor effect were the largest affected factors which affect the change of regional carbon emission at the regional level. However, there was a significant difference between carbon emission factor effect, energy intensity effect, and population size effect in three regions. The contribution ratio of the energy intensity effect in the eastern region was significantly smaller than in central and western regions, but its contribution ratio of population scale effect was significantly larger than the other two regions. The carbon emission factor effect of the central region was significantly larger than that of the eastern and western regions, and its population scale effect was almost 0. We would analyze in-depth the decomposed results of carbon emission from three aspects as technology, residents' consumption, and population factors due to the above characteristics of decomposed effects in the three regions.

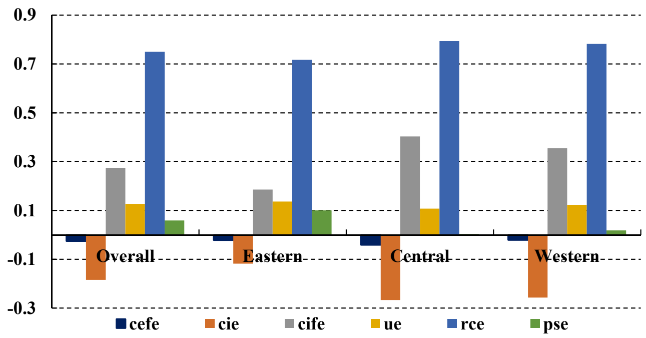

Figure 3. Contribution ratios of six decomposed effects on the increasing of regional carbon emission.

Firstly, the technical factors include two effects of carbon emission factor effect and energy intensity effect, their change tendency is shown in Figure 4. The influence of carbon emission factor and energy intensity on change of the regional carbon emission was negative overall during the sample period. Where, in 2003–2006, the contribution value in the three regions was around 0, they showed an obvious downward tendency in 2007–2012. It indicated that the effect of "technical emission reduction" in the three regions was gradually emerging and strengthening since 2007. The possible explanation is that after the implementation of the Kyoto Protocol, which was drawn up at the global climate conference of Montreal in 2005, the Chinese government positively implemented a low carbon economy policy on the two levels of technology and policy, and obtained the initial effect in 2007. In addition, carbon emission factor effect and energy intensity effect of the central region was always lower than in the eastern and western regions from 2006 to 2012. Namely, contribution of carbon emission factor effect and energy intensity effect on reduction of carbon emission in the central region was the largest. It showed that technological progress of carbon emission in the central region was higher than in the eastern and western regions. The possible reason was that the foundation of energy utilization technology in the east was better, and led to technological progress becoming more difficult. While the foundation of the economy in the western region was poor, it caused a lack of conditions conducive to technological progress.

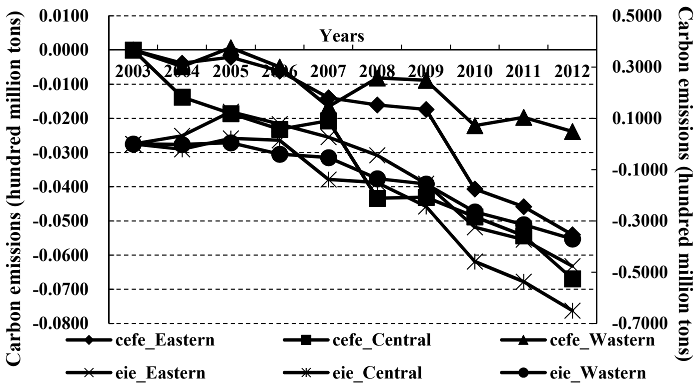

Figure 4. Change tendencies of energy intensity effect and carbon emission factor effect in three areas in 2003–2012.

Carbon emission factor effect was much lower than energy intensity effect; the main reason was that carbon emission coefficients of different types of energy were constant in this paper, and change of carbon emission factor was from the adjustment of energy structure, while we could find that the energy consumption in China was still mainly coal and petroleum during the sample period, according to statistical data from the *China Statistical Yearbook* [1] in 2004–2013. The proportion of consumption of coal and petroleum in Chinese total energy consumption decreased 2.5% and 2.2%, respectively, in 2012 compared to 2003, while the proportion of clean energy (non-fossil energy) rose only 1.2%, indicating that adjustment of energy structure was minimal. At the provincial level, the proportion of coal consumption declined 14.29% in Shanxi province, which was far higher than the national average. This led its carbon emission factor effect to become larger than other provinces, and this result was also in accordance with the above conclusion. On the other hand, the regional energy intensity continued to decline significantly in recent years due to the strict implementation of "energy saving and emission reducing" policy. It led to the effective reduction of regional carbon emission; the energy intensity effect was much higher than carbon emission factor effect.

Residents' consumption factors include consumption inhibitory factor effect and residents' consumption effect. Figure 5 presented the change tendency of the above two effects from 2003–2012. Influence of consumption inhibitory factor effect on the change of carbon emission in three regions exhibited an upward trend during the sample period, and did not show its inhibitory effect because its impact was positive. According to the expenditure approach definition of GDP, regional GDP was equal to the sum of residents' consumption, government consumption, fixed-asset investment, and net export, so the change direction of the consumption inhibitory factor was the same as summing government consumption, fixed-asset investment, and net export of domestic demand in Chinese economic development, and caused the reverse change relation between regions. Calculation results of consumption inhibitory factor effect show that the carbon emission intensity of the industry dimension of residents' consumer goods may be lower than the other three economic dimensions. Namely, the reduction of the consumption ratio would cause the rise of government consumption, fixed-asset investment, and net export when the economic output was fixed, and then promote the increase of total carbon emissions. However, according to the *China Statistical Yearbook* [1], although the total residents' consumption and per capita consumption increased, respectively, 6.8084 trillion and 4.8810 thousand RMB from 2003 to 2012, the residents' consumption ratio dropped from 34.25% to 27.29%, which indicated that it was a lack residents' consumption ratio and carbon emission. Therefore, the residents' consumption ratio dropped to 3.15% in the central region, which was much higher than the eastern and western areas. Its consumption inhibitory factor effect was also significantly higher than that of the eastern and western areas during this period.

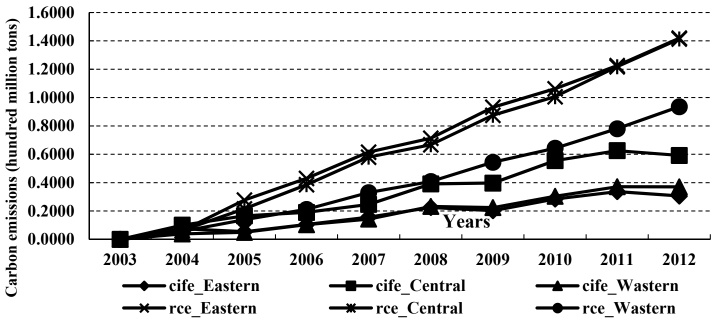

Figure 5. Change tendencies of consumption inhibitory factor effect and residents' consumption effect in three areas in 2003–2012.

The contribution value of residents' consumption on change of regional carbon emission was the maximum in absolute terms, and it was the most important influencing factor. Figure 5 showed that residents' consumption effect in three regions were 0.1419, 0.1413, and 0.0936 billion tons in 2012, and they clearly rose during the sample period; namely, the rising of per capita consumption caused carbon emission to increase 0.1419, 0.1413, and 0.0936 billion tons, respectively, in the eastern, central, and western areas. Residents' consumption effect in the western region was always much lower than that of the eastern and central areas in 2003–2012. The possible explanation could be that the economic development level and its growth rate in the western area was much lower than the other two regions, which caused its growth rate of per capita consumption to be much less than the eastern and central areas.

Equation (13) in this paper divided residents' consumption effect into two parts as residents' basic living and non-basic living consumption effect (*brce*, *nbrce*). Residents' basic living consumption effect represents the effects of five kinds of basic living consumption (food, clothing, housing, household appliances and services, transportation, and communication) on changes in carbon emission, while residents' non-basic living consumption effect represents the effects of other kinds of consumption on change in regional carbon emission. The results are shown in Figure 6.

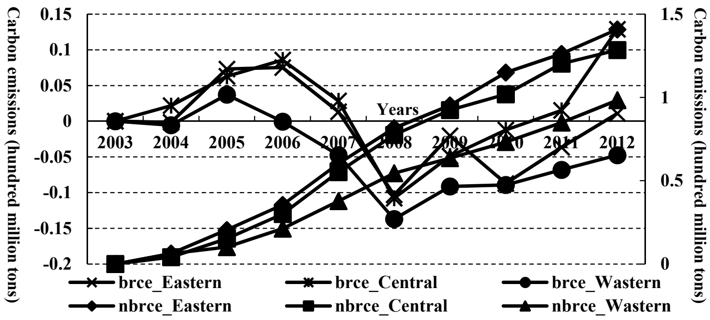

Figure 6. Change tendency of consumption structure in three areas from 2003 to 2012.

Figure 6 showed that there was a significant difference between impacts of residents' basic living consumption and residents' non-basic living consumption on change in regional carbon emission. The change tendency of residents' basic living consumption effect was similar to residents' consumption effect. Contribution values of residents' basic living consumption on change of regional carbon emission in eastern, central, and western areas were 0.1409, 0.1284, and 0.0983 billion tons by 2012. While residents' non-basic living consumption effect in three areas changed as graphic "N" around 0; it exhibited a fluctuating upward trend in 2003–2005 and in 2009–2012, and appeared to fluctuate down in 2006–2008. Influence of residents' non-basic living consumption effect on regional carbon emission presented as a weak negative effect, so the main source of residents' consumption effect was the residents' basic living consumption effect. There may be two reasons for this phenomenon. First, the proportion of residents' non-basic living consumption in residents' living consumption was very small. According to the statistical data, it was less than 20% in many provinces, and still kept decreasing. Second, residents' non-basic living consumption corresponded with education, entertainment and other service industries. Zhang [46] found that energy efficiency of education, entertainment and other service industries was high; namely, unit consumption of these industries consumed less energy, and then carried less carbon emission. Therefore, impact of change of residents' non-basic living consumption on change of carbon emission was relatively weak.

Figure 7 offered impact of population factors on change of carbon emission in three regions, mainly including two aspects: urbanization effect and population scale effect. According to Figure 7, the contribution of urbanization on carbon emission in the eastern, central, and western areas in China was 0.0236, 0.0199, and 0.0143 billion tons, respectively, from 2003 to 2012. Contribution of change of population size on carbon emission was 0.0196, 0.0030, and 0.0024 billion tons, respectively. Obviously, the urbanization effect was much larger than population scale effect in all the three regions, and demographic urbanization had become the main population factor which affects the change of carbon emission during the sample period. In addition, although the population scale effect was positive in central and western regions overall, its contribution was always close to 0, which was significantly lower than the population scale effect in the eastern area, and it manifested as a negative effect in the central area from 2005 to 2008. According to the conclusion of Cai [47], there was always an obvious population "Eastern aggregation" phenomenon in China since 1990s, especially the central region which was close to the eastern region, and the phenomenon of population flow to the eastern area was more obvious. It may be the main reason for the above characteristics in regional population scale effect.

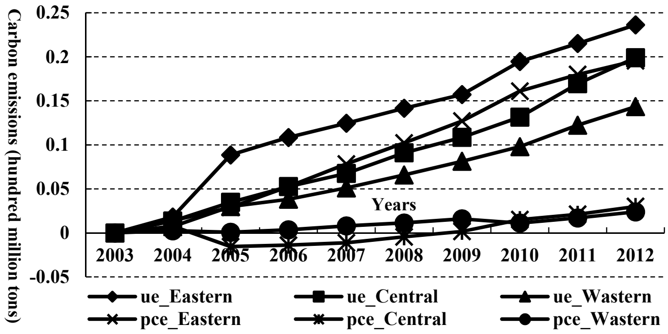

Figure 7. Change tendencies of urbanization effect and population scale effect in three areas from 2003 to 2012.

5. Empirical Results and Discussion

According to the previous study, population structure change has a great impact on the change of carbon emission. In this paper, we took seven indicators to represent population structure. Firstly, we selected the children dependency ratio (*children*) and the elderly people dependency ratio (*elderly*) to refer to the regional population age structure. The existing studies showed that, due to higher income level and the strong consumption demand of the middle-aged population, their per capita carbon emission was obviously higher than that of children and the elderly [5,28,29]. Therefore, we expected that the regression coefficients of these two indicators were negative. Secondly, we used the sex ratio of the total population (*sex*) to refer to the regional population sex structure. Due to the different consumption preferences between men and women, population sex structure also affected regional carbon emission. Thirdly, we used proportion of the population of senior high school (*senior*) and the proportion of the population of college and above (*college*) to refer to the regional population education structure. Generally, income of residents was increased with the increasing of a high-degree education population, thus causing the growth of residents' consumption ability and carbon emissions. However, high-degree education would also improve residents' environmental protection consciousness. Therefore, we believed that the effect of population education structure on carbon emission was uncertain. The data for the above five indicators are from the *China Statistical Yearbook* [1]. Fourthly, we used the proportion of employees in state-owned units in total Chinese urban employment (*occupation*) to refer to the regional population occupation structure. Compared with other employees, employees in state-owned units have more stable income and old-age security. It leads to the different consumption attitude between them and other employees, which affected regional carbon emission. Its data is from the *China Labour Statistical Yearbook* [3]. Finally, we used the proportion of urban population (*urban*) to refer to the population structure of urban and rural areas. Obviously, the income level and consumption capacity of rural residents were far behind the urban residents. This suggests that per capita carbon emission of rural residents was significantly less than urban residents, so the population structure of urban and rural areas was also an important factor which affected regional carbon emission [33–35]. This data is also from the *China Statistical Yearbook* [1].

In order to validate the relationship between change in population structure and carbon emission, we needed to conduct regression analysis. We used the total effect of change of regional carbon emission (ΔC) as the dependent variable, and took the seven indicators (*children*, *elderly*, *sex*, *senior*, *college*, *occupation*, *urban*) which referred to change of regional population structure in China as the independent variables. We then used regional GDP (*GDP*) and regional population scale (*population*) as controlled variables, conducted regression analysis of the effect of population structure change on the change in carbon emission. The regression model was as Equation (17):

$$\Delta C = \alpha + \beta_1 children + \beta_2 elderly + \beta_3 sex + \beta_4 senior + \beta_5 college + \beta_6 occupation + \beta_7 urban + \beta_8 GDP + \beta_9 population + \varepsilon \quad (17)$$

where: α was a constant, β_i ($i = 1, \ldots, 9$) and represented the regression coefficient of the variable, and ε represented random error.

Table 2 shows the correlation matrix of the variables. We find that the dependent variable is strongly correlated with each independent variable, and the correlation coefficients between independent variables are relatively weak.

Table 2. Correlation matrix of variables.

Variables	ΔC	*Children*	*Elderly*	*Sex*	*Senior*	*College*	*Occupation*	*Urban*	*GDP*	*Population*
ΔC	1.000									
children	−0.832	1.000								
elderly	−0.327	−0.140	1.000							
sex	−0.117	−0.154	0.159	1.000						
senior	−0.452	0.182	−0.212	−0.236	1.000					
college	−0.367	0.169	−0.176	−0.233	−0.041	1.000				
occupation	−0.463	0.220	−0.118	−0.263	0.160	0.157	1.000			
urban	0.480	−0.245	0.245	−0.064	−0.171	−0.116	−0.291	1.000		
GDP	0.555	0.286	−0.300	0.006	0.185	0.251	0.305	−0.356	1.000	
population	0.568	0.342	−0.294	−0.113	0.305	0.174	0.218	−0.163	0.317	1.000

In order to avoid spurious regression, this paper used Levin, Lin, and Chut, Fisher-ADF and Im, Pesaran, and Shin methods to complete the unit root test. Its results are shown in Table 3. Results show that the total effect of change of carbon emission (ΔC) was 0-stage integration, lower than the integrated stage of all the other variables. Thus, the sample was suitable for regression analysis.

Table 3. Unit root test of variables.

		Level			1st Difference		
Test		(c, t)					
Variables	Parameters	LLC	Fisher-ADF	IPS	LLC	Fisher-ADF	IPS
ΔC	Statistics (Pro.)	−16.0600 *** (0.0000)	108.6670 *** (0.0000)	−1.5614 * (0.0592)	−14.4271 *** (0.0000)	97.6317 *** (0.0015)	−1.5265 * (0.0613)
children		−9.2836 *** (0.0000)	106.7150 *** (0.0002)	−0.7277 (0.2334)	−32.4082 *** (0.0000)	216.4500 *** (0.0000)	−5.8521 *** (0.0000)
elderly		−11.0706 *** (0.0000)	80.8367 ** (0.0378)	−0.7182 (0.2363)	−9.3649 *** (0.0000)	80.6729 ** (0.0388)	−1.4363 * (0.0713)
sex		−12.2982 *** (0.0000)	114.0410 *** (0.0000)	−1.7438 ** (0.0406)	−21.3471 *** (0.0000)	109.3150 *** (0.0001)	−2.2791 ** (0.0113)
senior		−10.8482 *** (0.0000)	88.6095 *** (0.0096)	−0.6717 (0.2509)	−8.6645 *** (0.0000)	99.7102 *** (0.0010)	−1.4869 * (0.0643)
college		−9.6667 *** (0.0000)	79.6100 ** (0.0460)	−0.3295 (0.3709)	−14.6147 *** (0.0000)	125.5700 *** (0.0000)	−2.0845 ** (0.0186)
occupation		−10.1579 *** (0.0000)	85.4663 ** (0.0171)	−0.8982 (0.1845)	−12.8208 *** (0.0000)	105.0820 *** (0.0003)	−1.3890 * (0.0824)
urban		−17.9312 *** (0.0000)	112.8150 *** (0.0000)	−3.0377 *** (0.0012)	−26.5032 *** (0.0000)	194.4340 *** (0.0000)	−6.1255 *** (0.0000)
GDP		−4.5980 *** (0.0000)	24.6834 (1.0000)	2.2162 (0.9867)	−48.9063 *** (0.0000)	112.7480 *** (0.0000)	−3.1260 *** (0.0009)
population		−7.3813 *** (0.0000)	67.1597 (0.2452)	0.4411 (0.6704)	−3.5134 *** (0.0002)	88.2176 ** (0.0103)	−2.0025 ** (0.0224)
ΔC_{ei}		−26.8766 *** (0.0000)	139.5560 *** (0.0000)	−3.7129 *** (0.0001)	−48.5369 *** (0.0000)	177.8920 *** (0.0000)	−7.6320 *** (0.0000)
ΔC_{b-ib}		−3.3387 *** (0.0004)	152.1686 *** (0.0000)	−1.4127 * (0.0734)	−14.4752 *** (0.0000)	109.1800 *** (0.0001)	−1.6076 * (0.0540)
ΔC_{cif}		−11.5972 *** (0.0000)	92.0104 ** (0.0049)	−1.5105 * (0.0625)	−16.5986 *** (0.0000)	117.8310 *** (0.0000)	−2.0217 ** (0.0216)

*, **, ***, respectively represented 1%, 5%, 10% of significance (same in below), (c, t) represented the test included intercept and trend.

The regression results were shown in Table 4.

Table 4. Regression results by using the panel data.

Dependent Variable	ΔC (Model I)		ΔC_{ei} (Model II)		ΔC_{b-ib} (Model III)		ΔC_{cif} (Model IV)	
Model	**Random Effect**	**Fixed Effect**	**Random Effect**	**Fixed Effect**	**Random Effect**	**Fixed Effect**	**Random Effect**	**Fixed Effect**
α	0.0435 (0.5635)	0.0404 (1.1053)	0.0860 * (1.7391)	0.0893 *** (3.4590)	−0.0507 (−0.9356)	−0.0542 * (−1.9466)	0.0175 (0.6590)	0.0124 (0.7796)
children	−0.5183 (−0.6576)	−0.2921 (−0.3532)	0.0497 (0.0904)	−0.0267 (−0.0457)	0.3410 (0.5736)	0.5643 (0.8955)	−0.9641 *** (−2.9198)	−0.8454 ** (−2.3562)
elderly	−3.7614 *** (−2.9769)	−4.1666 *** (−3.1737)	−0.5438 (−0.6158)	−0.9330 (−1.0068)	−2.7265 *** (−2.8558)	−2.7113 *** (−2.7103)	−0.5854 (−1.0998)	−0.5877 (−1.0318)
sex	−0.6393 (−1.0824)	−0.5301 (−0.8843)	−0.7065 * (−1.7013)	−0.5293 (−1.2508)	0.1372 (0.3060)	0.0893 (0.1954)	0.0035 (0.0139)	−0.0139 (−0.0536)
senior	−0.0132 (−0.0118)	−0.0167 (−0.0146)	−1.3958 * (−1.7748)	−1.4344 * (−1.7861)	0.4019 (0.4731)	0.4584 (0.5288)	1.0580 ** (2.2080)	0.9902 ** (2.0060)
college	−4.3014 *** (−4.5915)	−3.9709 *** (−4.0395)	−2.4658 *** (−3.7756)	−2.2253 *** (−3.2070)	−1.5444 ** (−2.1862)	−1.4575 * (−1.9458)	0.0191 (0.0487)	0.0295 (0.0691)
occupation	−1.7805 *** (−4.0319)	−1.8162 *** (−3.8919)	1.1680 *** (3.7999)	1.3068 *** (3.9672)	−1.4898 *** (−4.4799)	−1.6132 *** (−4.5368)	−1.2401 *** (−6.7425)	−1.3053 *** (−6.4469)
urban	2.1633 *** (2.8974)	2.4480 *** (3.0411)	0.7583 (1.4664)	1.0007 * (1.7612)	1.4307 ** (2.5551)	1.4542 ** (2.3708)	−0.7318 ** (−2.3870)	−0.6403 * (−1.8333)
GDP	1.1435 *** (15.1690)	1.0851 *** (13.6907)	−0.2825 *** (−5.3773)	−0.3258 *** (−5.8226)	1.0508 *** (18.4913)	1.0407 *** (17.2322)	0.3081 *** (9.7790)	0.2924 *** (8.5038)
population	3.9944 *** (3.1241)	3.6307 *** (2.7260)	0.6994 (0.7831)	0.9549 (1.0157)	4.1915 *** (4.3407)	4.1820 *** (4.1208)	4.3960 *** (8.1742)	4.1527 *** (7.1863)
F	165.4951 ***	117.0388 ***	49.2603 ***	30.2704 ***	244.4422 ***	109.7192 ***	77.1463 ***	42.6501 ***
Adj-R^2	0.8462	0.9425	0.6175	0.8053	0.8906	0.9389	0.7181	0.8547
Hausman Test	8.7323 (0.4623)		20.3562 ** (0.0158)		5.0647 (0.8286)		4.8763 (0.8450)	
LM test	10.9722 (0.2121)	11.3757 (0.2016)	12.9090 (0.1617)	12.5401 (0.1713)	12.1020 (0.1827)	11.9982 (0.1854)	11.7408 (0.1921)	11.8906 (0.1882)

Figures in brackets in the same row as "Hausman Test" indicated accompanying probability; other figures in brackets indicated statistical quantity T of the corresponding variables (same as below).

Table 4 showed that the Hausman test statistic of model I was 8.7323, and its probability was 0.4623. So the random effect model was more suitable to the sample. Results of the LM test illustrated that the regression residuals are stable, and the regression result is effective. Firstly, the regression coefficient of the regional elderly dependency ratio (*elderly*) was negative, and it had 1% significance, indicating that the ageing population would reduce carbon emission from energy consumption. Studies of Liddle *et al.* [28] and Okada [6] also obtained a similar conclusion. The possible explanation was that income of the elderly population gradually reduces with the growth of age, so their consumption scale and consumption levels were much lower than middle-aged or youth population, and then caused the decreasing of carbon emission. Secondly, the regression coefficient of the regional proportion of the population of college and above (*college*) was negative, and it had 1% significance, indicated that rising of population quality was helpful to decrease regional carbon emission, in contrast with the conclusion of Katircioğlu [10]. There may be two reasons to explain this result: the first, that the proportion of the highly educated population not only reflected the level of human capital, but also was the source of regional technology innovation. Thus, an increase in education was helpful to renew the energy utilization technology. The second, that this population could effectively fulfill the development concept of "energy-saving and emission-reducing", especially in the economic department of consumption, the highly educated population preferred to choose the environmentally friendly products. This was helpful to reduce carbon emission. Thirdly, the regression coefficient of the proportion of employees in state-owned units in total Chinese urban employment (*occupation*) was negative, and it had 1% significance, indicating that reducing the proportion of employees in state-owned units promoted the increasing of carbon emission, which was in contrast with the expectation of this paper. The proportion of employees in state-owned units reflected the proportion of the state-owned economy to some extent. Due to the inefficiency of state-owned economic departments, the rapid development of market economics caused the increasing of energy consumption, and then caused a rise in carbon emission. This explains why the regression coefficient of *occupation* was negative. Finally, the regression coefficients of regional population urban and rural structure (*urban*), regional total GDP (*GDP*) and regional total population (*Population*) were positive, and were all of 1% significance. This met our expectation completely, indicating that the development of urbanization, economic growth, and expansion of the regional population scale would promote the increasing of carbon emission from energy consumption.

In addition, the carbon emission factor effect (ΔC_{ci}) was decided by the energy emission coefficient and energy structure; the effect of population structure on it was small. Urbanization effect (ΔC_{u-r}) expressed the impact of change of urban and rural population on carbon emission. It was only related to the change of urban and rural population structure (*urban*), and population scale effect (ΔC_P) only expressed the impact of change of population scale on carbon emission. Obviously, the above three decomposed effects were hardly affected by the seven indices of population structure change. Therefore, energy intensity effect (ΔC_{ei}), residents' consumption effect (ΔC_{b-ib}) and consumption inhibitory factor effect (ΔC_{cif}) may be the main path which conducted the effect of change of population structure on change in carbon emission. Then we would take three decomposed effects (ΔC_{ei}, ΔC_{b-ib}, ΔC_{cif}) as dependent variables respectively to analyze the path which conducted the effect of change of population structure on change of carbon emission in the content of this paper below. The regression model was as Equation (18):

$$\begin{aligned}
\Delta C_{ei} &= \alpha_1 + \beta_1 children + \beta_2 elderly + \beta_3 sex + \beta_4 senior + \beta_5 college + \\
&\quad \beta_6 occupation + \beta_7 urban + \beta_8 GDP + \beta_9 population + \varepsilon_1 \\
\Delta C_{b-ib} &= \alpha_2 + \beta_1 children + \beta_2 elderly + \beta_3 sex + \beta_4 senior + \beta_5 college + \\
&\quad \beta_6 occupation + \beta_7 urban + \beta_8 GDP + \beta_9 population + \varepsilon_2 \\
\Delta C_{cif} &= \alpha_3 + \beta_1 children + \beta_2 elderly + \beta_3 sex + \beta_4 senior + \beta_5 college + \\
&\quad \beta_6 occupation + \beta_7 urban + \beta_8 GDP + \beta_9 population + \varepsilon_3
\end{aligned} \tag{18}$$

where α_i (i = 1, 2, 3) was a constant, β_i (i = 1, . . . ,9) which represented the regression coefficient of the variable, and ε_i (i = 1, 2, 3) represented random error. The regression results are shown in Table 3. The results showed that the Hausman test statistical quantity in model II was 20.3562, and it was of 5% significance. Thus, the fixed effect model was more suitable to model II, while we should select a random effect model in model III and model IV.

Firstly, in model II, regression coefficients of the regional proportion of the population of senior high school (*senior*) and the proportion of the population of college and above (*college*) indices were negative, and they were of 10% and 1% significance, respectively, indicating that improvement of the population quality was helpful to reduce the regional energy intensity effect (ΔC_{ei}). Energy intensity reflected the development of technology of energy utilization. The regression coefficient of the regional proportion of employees in state-owned units in the total Chinese urban employment (*occupation*) was positive, and it showed 1% significance, which indicated that the proportion of employees in state-owned enterprises hindered the advance of energy utilized technology. This result corresponded to the inefficiency of state-owned economic components. Regression coefficients of regional population urban and rural structure (*urban*) and total GDP (*GDP*) indices were of 10% and 1% significance, respectively, and the regression coefficient of regional total GDP (*GDP*) was negative, which indicated that improvement of the economy in China was helpful to promote the progress of energy utilized technology during the sample period.

Secondly, identical to model I, when ΔC_{b-ib} is taken as the dependent variable, the effect of the regional elderly people dependency ratio (*elderly*), proportion of the population of college and above (*college*), proportion of employees in state-owned units in total China urban employment (*occupation*), population urban and rural structure (*urban*), total GDP (*GDP*) and total population (*population*) indices were significant, and the sign of their regression coefficients were the same as in model I. This indicated that the population education structure, population occupation structure, and population urban and rural structure could further affect regional carbon emission from energy consumption through affecting residents' consumption scale and consumption levels.

Thirdly, in model IV, the regression coefficient of children dependency ratio (*children*) index was negative, and it showed 1% significance. Due to the low consumption capacity of the juvenile population, the increasing of the children dependency ratio (*children*) would inevitably cause the residents' consumption ratio to decrease, thereby reducing carbon emission from energy consumption. Contrary to the former three models, the regression coefficient of regional population urban and rural structure (*urban*) was negative, and it showed 10% significance, indicated that development of urbanization would reduce the consumption inhibitory factor effect (ΔC_{cif}). Although the development of urbanization has promoted the rising of the urban population, and increased the amount of residents' consumption, the residents' consumption ratio in provinces of China decreased continuously during the sample period according to the data of the *China Statistical Yearbook* [43]. Therefore, the contribution of urbanization development on the overall economy was stronger than on residents' consumption. This may explain why the regression coefficient of regional population urban and rural structure (*urban*) was negative. In addition, identical to model I and model III, the regression coefficients of *occupation*, *GDP*, and *population* all showed 1% significance.

Finally, through comparing the results of the above models, we found that population structure change affected change of regional carbon emission from energy consumption mainly through affecting residents' consumption ratio and consumption level. Population education structure affected change of regional carbon emission mainly by two paths as progress of energy utilized technology and change of residents' consumptive conception. Paths of impact of population occupation structure and population urban and rural structure all included progress of energy utilized technology, scale, and level of residents' consumption, residents' consumption ratio. Although the effect of population sex structure (sex ratio) index on regional carbon emission was always not significant, the sex ratio at birth in China was always higher than 115 during the sample period; this may cause serious gender imbalance in the future. It should catch our attention whether this phenomenon would have significant impact on carbon emission from energy consumption in China in the future.

Due to the large gap of change of carbon emission and its decomposed effects between three regions, this paper analyzed effect of population structure change on carbon emission and its decomposed effects in different regions by introducing dummy variables into Equation (17) and Equation (18). Dummy variables were set up as follows:

$$Eastern = \begin{cases} 1 & (Eastern) \\ 0 & (Other\ areas) \end{cases} \quad Central = \begin{cases} 1 & (Central) \\ 0 & (Other\ areas) \end{cases} \tag{19}$$

ΔC, ΔC_{ei}, ΔC_{b-ib}, ΔC_{if} were taken as dependent variables, respectively, introduced dummy variables into the regression model, and obtained the results as shown in Table 5.

Table 5. Regression results by using the panel data (including dummy variables).

Dependent Variables	**ΔC (Model V)**	**ΔC_{ei} (Model VI)**	**ΔC_{b-ib} (Model VII)**	**ΔC_{if} (Model VIII)**
Model	**Random effect**	**Random effect**	**Random effect**	**Random effect**
α	−0.0533 (−0.4274)	0.0103 (0.1386)	−0.0645 (−0.7419)	0.0240 (0.5932)
children	−0.4754 (−0.5997)	0.0728 (0.1323)	0.3652 (0.6098)	−0.9501 *** (−2.8577)
elderly	−3.9236 *** (−3.0862)	−0.7000 (−0.7908)	−2.7423 *** (−2.8497)	−0.5351 (−0.9970)
sex	−0.5990 (−1.0116)	−0.6774 (−1.6297)	0.1377 (0.3060)	−0.0025 (−0.0100)
senior	0.0743 (0.0662)	−1.2794 (−1.6241)	0.4196 (0.4919)	1.0231 ** (2.1251)
college	−4.2848 *** (−4.5513)	−2.5008 *** (−3.8324)	−1.5358 ** (−2.1598)	0.0424 (0.1075)
occupation	−1.7906 *** (−4.0323)	1.1457 *** (3.7308)	−1.4996 *** (−4.4761)	−1.2306 *** (−6.6494)
urban	2.2128 *** (2.9322)	0.7640 (1.4727)	1.4406 ** (2.5377)	−0.7102 ** (−2.2847)
GDP	1.1345 *** (14.8856)	−0.2842 *** (−5.3693)	1.0489 *** (18.2049)	0.3058 *** (9.5512)
population	4.0629 *** (3.1490)	0.5210 (0.5798)	4.1958 *** (4.2958)	4.2943 *** (7.8786)
Eastern	0.2061 * (1.7130)	0.1829 * (1.8795)	0.0250 (0.2182)	−0.0352 (−0.6699)
Central	0.0406 (0.1999)	−0.0132 (−0.1109)	0.0138 (0.0987)	0.0413 (0.6451)
F	136.1431 ***	40.7581 ***	199.8641 ***	63.3061 ***
Adj-R^2	0.8468	0.6192	0.8905	0.7181
Hausman Test	5.8078 (0.7590)	14.7004 * (0.0995)	3.2680 (0.9527)	3.4778 (0.9423)

According to the results of the Hausman test, the random effect model was more suitable to this study. Due to space limitations, we only provide the regression results of the random effect model in this paper; the author could provide regression results of the fixed effect model if necessary.

Table 5 showed that the regression coefficient of *Eastern* in model V was 0.2061, and it was significant. This indicated that change of carbon emission from energy consumption in the eastern region was significantly higher than that in the central and western regions. The regression coefficient of *Eastern* in model VI was 0.1829, and it was also significant, while the effect of dummy variables was not significant in the other models. This result further showed that the foundation of energy utilization technology in the east was better, and met the above conclusion.

6. Conclusions

On the basis of Kaya identity, this paper expanded the LMDI model through introducing population urbanization, residents' consumption and other factors, and decomposed the change of carbon emission in China into six effects: carbon emission factor effect, energy intensity effect, consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect. It then explored contribution ratios and action mechanism of the above six effects on change of carbon emission. Then, we analyzed the effect of population structure change on carbon emission by taking 2003-2012 as a sample period, and combined this with the panel data of 30 provinces in China. The main conclusions of this paper are as follows:

(1) In 2003–2012, total carbon emission in China increased by 4.2117 billion tons. Consumption inhibitory factor effect, urbanization effect, residents' consumption effect, and population scale effect could promote the increasing of carbon emission, while the influence of carbon emission factor effect and energy intensity effect on carbon emission were negative, indicating that Chinese energy technology utilized during the samples was improved and reached the effect of "technical carbon emission reduction" to some extent. Specifically, the contribution ratio of residents'

consumption effect affected change of carbon emission was greatest, which reached 74.96%, followed by the consumption inhibitory effect and energy intensity effect. Their contribution ratios were 27.44% and −18.46%, respectively. The contribution ratio of impact of urbanization effect, population scale effect and carbon emission factor effect on carbon emission was 12.700%, 5.90%, and −2.54% respectively.

(2) Firstly, there was a significant difference between the carbon emission factor effect, energy intensity effect, and population scale effect in the three areas. Contribution ratio of energy intensity effect in the eastern region was significantly smaller than the central and western areas, while contribution ratio of its population scale effect was larger than the other two regions. Carbon emission factor effect of the central area was significantly higher than that in the eastern and western regions, and its population scale effect was close to 0. Secondly, the influences of carbon emission factor and energy intensity on the changing of regional carbon emission were all negative. The carbon emission factor effect and energy intensity effect in the three regions were around 0 from 2003 to 2006, while in 2007–2012 they all showed obvious decline. Thirdly, influences of the consumption inhibitory factor effect on changing of regional carbon emission in three areas showed a fluctuating upward trend, their effect were positive and did not show their inhibition. The residents' consumption effect in the three regions showed a clear upward trend, and the residents' consumption effect in the eastern, central, and western regions were 0.1419, 0.1413, and 0.0936 billion tons in 2012, respectively. The residents' consumption effect became the most important influencing factor which affected change of carbon emission and its contribution ratio was the greatest. The main source of the residents' consumption effect in the three regions was the residents' basic living consumption effect, while residents' non-basic living consumption effect in the three areas changed as a graphic "N" around 0; it showed a fluctuating upward trend in 2003–2005 and in 2009–2012, and appeared to fluctuate downwards in 2006–2008. Finally, the "eastern aggregation" phenomenon of population caused the population scale effect of the eastern area to be obviously larger than the central and western areas. The urbanization effect in all three regions were obviously larger than the population scale effect, which indicated that demographic urbanization has become the main population factor which affected the change of carbon emission.

(3) Secondly, the impact of regional people dependency ratio on regional carbon emission was negative and significant, as was the proportion of the population of college and above, and the proportion of employees in state-owned units in total Chinese urban employment, while the effect of regional population urban and rural structure, total GDP and total population were positive and significant. Based on the analysis of the decomposition effects, we found that population structure change affected change in regional carbon emission from energy consumption mainly through affecting residents' consumption ratio and consumption levels. Population education structure affected change of regional carbon emission mainly by two paths, as progress of energy utilized technology and change of residents' consumptive conception. While the path of the impact of population occupation structure and population urban and rural structure all included progress of energy utilized technology, scale, and the level of residents' consumption and residents' consumption ratio, the effect of population sex structure (sex ratio) index on regional carbon emission was always non-significant. Finally, we found that the change of carbon emission in the eastern region was significantly higher than that in the central and western regions when dummy variables were introduced into the regression model. The foundation of energy utilized technology in the eastern region was also significantly better than in the other two regions.

Acknowledgments: This work was financially supported by Funding of Jiangsu Social Sciences (No. 12EYA001), Funding of Jiangsu University Philosophy and Social Science (No. 11ZDIXM051), Funding of Anhui Humanities and Social Sciences (No. SK2014A099), Funding of Jiangsu Innovation Program for Graduate Education (No. KYZZ_0107 & No. CXLX12_0178), China Scholarship Council: "Graduate Programs of National Construction High Level University in 2014".

Author Contributions: Wen Guo and Tao Sun wrote the paper, Wen Guo and Hongjun Dai analyzed the data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. National Bureau of Statistics of China. *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2001–2014.
2. Zhuang, Y.E.; Zhang, L.P. *China Commonly Used Population Data Set Since 1990*; China Population Press: Beijing, China, 2003.
3. National Bureau of Statistics of China. *China Labour Statistical Yearbook*; China Statistics Press: Beijing, China, 2001–2014.
4. Wang, Q. Effects of urbanization on energy consumption in China. *Energy Policy* **2014**, *65*, 332–339. [CrossRef]
5. Liddle, B. Consumption-driven environmental impact and age structure change in OECD countries: A cointegration-STIRPAT analysis. *Demogr. Res.* **2011**, *30*, 749–770. [CrossRef]
6. Okada, A. Is an increased elderly population related to decreased CO_2 emissions from road transportation? *Energy Policy* **2012**, *45*, 286–292. [CrossRef]
7. Menz, T.; Welsch, H. Population aging and carbon emissions in OECD countries: Accounting for life-cycle and cohort effects. *Energy Econ.* **2012**, *34*, 842–849. [CrossRef]
8. Zhu, H.M.; You, W.H.; Zeng, Z. Urbanization and CO_2 emissions: A semi-parametric panel data analysis. *Econ. Lett.* **2012**, *3*, 848–850. [CrossRef]
9. Knight, K.W.; Rosa, E.A.; Schor, J.B. Could working less reduce pressures on the environment? A cross-national panel analysis of OECD countries, 1970–2007. *Glob. Environ. Chang.* **2013**, *23*, 691–700. [CrossRef]
10. Katircioğlu, S.T. Estimating higher education induced energy consumption: The case of Northern Cyprus. *Energy* **2014**, *66*, 831–838. [CrossRef]
11. Cellura, M.; Longo, S.; Mistretta, M. Application of the structural decomposition analysis to assess the indirect energy consumption and air emission changes related to Italian households consumption. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1135–1145. [CrossRef]
12. Zhao, X.; Li, N.; Ma, C. Residential energy consumption in urban China: A decomposition analysis. *Energy Policy* **2012**, *41*, 644–653. [CrossRef]
13. Hoekstra, R.; Bergh, J.C.J.M. Comparing Structural and Index Decomposition Analysis. *Energy Econ.* **2003**, *25*, 39–64. [CrossRef]
14. Ang, B.W. Decomposition Analysis for Policymaking in Energy: Which is the Preferred Method. *Energy Policy* **2004**, *32*, 1131–1139. [CrossRef]
15. Ang, B.W.; Zhang, F.Q. A Survey of Index Decomposition Analysis in Energy and Environmental Studies. *Energy* **2009**, *25*, 1149–1176. [CrossRef]
16. Ang, B.W.; Huang, H.C.; Mu, A.R. Properties and linkages of some index decomposition analysis methods. *Energy Policy* **2009**, *11*, 4624–4632. [CrossRef]
17. Choi, Y.; Zhang, N.; Zhou, P. Efficiency and abatement costs of energy-related CO_2 emissions in China: A slacks-based efficiency measure. *Appl. Energy* **2012**, *98*, 198–208. [CrossRef]
18. Zhang, N.; Choi, Y. Total-factor carbon emission performance of fossil fuel power plants in China: A metafrontier non-radial Malmquist index analysis. *Energy Econ.* **2013**, *40*, 549–559. [CrossRef]
19. Su, B.; Ang, B.W. Structural decomposition analysis applied to energy and emissions: Some methodological developments. *Energy Econ.* **2012**, *34*, 177–188. [CrossRef]
20. Zhang, N.; Zhou, P.; Choi, Y. Energy efficiency, CO_2 emission performance and technology gaps in fossil fuel electricity generation in Korea: A meta-frontier non-radial directional distance function analysis. *Energy Policy* **2013**, *56*, 653–662. [CrossRef]
21. Rosa, E.A.; York, R.; Dietz, T. Tracking the anthropogenic drivers of ecological impacts. *AMBIO A J. Hum. Environ.* **2004**, *8*, 509–512. [CrossRef]
22. O'Neill, B.C.; Liddle, B.; Jiang, L.; Smith, K.R.; Pachauri, S.; Dalton, M.; Fuchs, L. Demographic change and carbon dioxide emissions. *Lancet* **2012**, *380*, 157–164. [CrossRef]
23. Wang, P.; Wu, W.; Zhu, B.; Wei, Y. Examining the impact factors of energy-related CO_2 emissions using the STIRPAT model in Guangdong Province, China. *Appl. Energy* **2013**, *106*, 65–71.
24. Satterthwaite, D. The Implications of Population Growth and Urbanization for Climate Change. *Environ. Urban.* **2009**, *2*, 545–567. [CrossRef]

25. Yao, C.; Chen, C.; Li, M. Analysis of rural residential energy consumption and corresponding carbon emissions in China. *Energy Policy* **2012**, *41*, 445–450. [CrossRef]
26. Wang, L.; Chen, Z.; Ma, D.; Zhao, P. Measuring carbon emissions performance in 123 countries: Application of minimum distance to the strong efficiency frontier analysis. *Sustainability* **2013**, *5*, 5319–5332. [CrossRef]
27. York, R. Demographic trends and energy consumption in European Union Nations, 1960–2025. *Soc. Sci. Res.* **2007**, *3*, 855–872. [CrossRef]
28. Liddle, B.; Lung, S. Age-structure, urbanization, and climate change in developed countries: Revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Popul. Environ.* **2010**, *5*, 317–343. [CrossRef]
29. Lugauer, S.; Jensen, R.; Sadler, C. An estimate of the age distribution's effect on carbon dioxide emissions. *Econ. Inq.* **2014**, *2*, 914–929. [CrossRef]
30. Zagheni, E. The leverage of demographic dynamics on carbon dioxide emissions: Does age structure matter? *Demography* **2011**, *1*, 371–399. [CrossRef] [PubMed]
31. Laureti, T.; Montero, J.M.; Fernández-Avilés, G. A local scale analysis on influencing factors of NOx emissions: Evidence from the Community of Madrid, Spain. *Energy Policy* **2014**, *74*, 557–568. [CrossRef]
32. Jorgenson, A.K. Does foreign investment harm the air we breathe and the water we drink? A cross-national study of carbon dioxide emissions and organic water pollution in less-developed countries, 1975 to 2000. *Organ. Environ.* **2007**, *2*, 137–156. [CrossRef]
33. Jorgenson, A.K. The sociology of ecologically unequal exchange and carbon dioxide emissions, 1960–2005. *Soc. Sci. Res.* **2012**, *2*, 242–252. [CrossRef] [PubMed]
34. Jorgenson, A.K.; Clark, B. Assessing the temporal stability of the population/environment relationship in comparative perspective: A cross-national panel study of carbon dioxide emissions, 1960–2005. *Popul. Environ.* **2010**, *1*, 27–41. [CrossRef]
35. Jorgenson, A.K.; Clark, B. Are the Economy and the Environment Decoupling? A Comparative International Study, 1960–2005. *Am. J. Soc.* **2012**, *1*, 1–44. [CrossRef]
36. Poumanyvong, P.; Kaneko, S. Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. *Ecol. Econ.* **2010**, *2*, 434–444. [CrossRef]
37. Martinez-Zarzoso, I.; Maruotti, A. The impact of urbanization on CO_2 emissions: Evidence from developing countries. *Ecol. Econ.* **2011**, *70*, 1344–1353. [CrossRef]
38. Poumanyvong, P.; Kaneko, S.; Dhakal, S. Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries. *Energy Policy* **2012**, *46*, 268–277. [CrossRef]
39. Fang, W.; Miller, S.; Yeh, C.C. The effect of ESCOs on energy use. *Energy Policy* **2012**, *51*, 558–568. [CrossRef]
40. Mishra, V.; Smyth, R.; Sharma, S. The energy-GDP nexus: Evidence from a panel of Pacific Island countries. *Resour. Energy Econ.* **2009**, *3*, 210–220. [CrossRef]
41. Hossain, S. Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* **2011**, *11*, 6991–6999. [CrossRef]
42. Al-mulali, U.; Fereidouni, H.G.; Lee, J.Y.M.; Sab, C.N.B.C. Exploring the relationship between urbanization, energy consumption, and CO_2 emission in MENA countries. *Renew. Sustain. Energy Rev.* **2013**, *23*, 107–112. [CrossRef]
43. Liddle, B. Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. *Popul. Environ.* **2014**, *3*, 286–304. [CrossRef]
44. Song, M.L.; Zhou, Y.X. Analysis of Carbon Emissions and Their Influence Factors Based on Data from Anhui of China. *Comput. Econ.* **2014**, *1*, 1–16. [CrossRef]
45. National Bureau of Statistics of China. *China Energy Statistical Yearbook*; China Statistics Press: Beijing, China, 2004–2013.
46. Zhang, J.F.; Deng, W. Industrial structure change and its eco-environmental influence since the establishment of municipality in Chongqing, China. *Procedia Environ. Sci.* **2010**, *2*, 517–526. [CrossRef]
47. Cai, F.; Lu, Y. Population change and resulting slowdown in potential GDP growth in China. *China World Econ.* **2013**, *2*, 1–14. [CrossRef]