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Impact of Population Aging on Carbon Emission in China: A Panel Data Analysis

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Received: 8 June 2018; Accepted: 11 July 2018; Published: 13 July 2018

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Abstract: The impact of population structure on carbon emission has always been a key area of research in modern society. In this paper, we propose a new expanded STIRPAT model and panel co-integration method to analyze the relationship between population aging and carbon emission, based on the provincial panel data in China from 1999 to 2014. Empirical results show that there exists a significant inverted U-shaped curve between the population aging and carbon emission. There also exist regional discrepancies, where the impact of the population aging on carbon emission in the eastern region is significantly positive. By contrast, a negative relationship arises in the central and western regions. Finally, several suggestions for low carbon development are provided.

Keywords: population aging; carbon emission; panel data analysis; co-integration analysis; STIRPAT model

1. Introduction

With the worsening global environment, extreme climates, for instance the sea level rising, climate warming and drought, frequently occur. The global climate change caused by the greenhouse gas emission has attracted wide attention from all over the world. The fifth assessment report given by Intergovernmental Panel on Climate Change (IPCC) pointed out that the global temperature had been rising significantly since the industrial revolution [1]. The increase of carbon emission caused by fossil fuels burning in human production and living life is the main cause of the climate change. China's economy develops rapidly in the past 30 years, making its GDP rank second, and carbon emission rank first in the world (accounting for 28% of global carbon emission in 2011) [2]. In 2013, China's per capita carbon emission first exceeded the EU at 7.2 tons/person [3]. As the largest carbon emitter in the world, China is facing huge pressure on energy-saving and emission reduction. In the National Plan for Addressing Climate Change (2014–2020), a mandatory provision indicates that unit GDP carbon dioxide emission in China by 2020 must be reduced 40–45% compared tothat in 2005 [4]. Meanwhile, China's population age structure is undergoing rapid change in recent decades. The number of the elderly (over 60 years) grew from 126 million to 153 million during 2000 to 2007 and its proportion increased from 10.2% to 11.6%, accounting for 21.4% of the world, which was equivalent to the number of elderly in Europe [5]. By the end of 2017, the number of elderly was more than 240 million, making up 17.3% of the total population [5]. "China report on the development on silver industry (2014)" predicts that the number of the elderly will exceed 400 million around 2033 and 500 million by 2050 [6]. The advent of the "silver tide", with no doubt, will bring great impact on China's economic, social, political and cultural development.

The State of World Population 2009 issued by United Nations Population Fund, pointed out that the greenhouse gas emission, associated with factors of age structure, population growth rate, the proportion of urban population, gender ratio, per capita income, etc. had profound impact on climate change [7]. Human's production and consumption are directly influenced by population age structure; meanwhile, the production and consumption can affect carbon emission through final energy consumption. Therefore, it can be concluded that aging plays a crucial role on the carbon emission. On the one hand, the population aging will cause a reduction of effective supply of labor, thus slowing down the growth of economy. Further, considering the positive association between economic growth and carbon emission [8–10], aging may contribute to the reduction of energy consumption and carbon emission. However, on the other hand, Yeh andLiao (2017) found that aging people tended to consume more energy-intensive products, which indicated that aging might promote the growth of carbon emission [11]. Hence, the relationship between aging and carbon emission is not clear enough. Research wouldshed some new light on the relationship between population aging and carbon emission. With the implementation of the one-child policy, China's population growth rate has been strictly controlled. Population aging has become the most significant trend in China in recent years. Under this background, research onthe impact of population aging on China's carbon emission wouldbring important practical value for policy makers on drafting and implementing carbon emission reduction policy, andwouldhave practical significance to the sustainable development of China's economy, and the transformation and the upgrading of industrial structure.

The rest of this paper is organized as follows. The influencing factors analysis of carbon emission is included in Section 2. Section 3 is devoted to the materials and methods, including the STIRPAT model and panel co-integration method. The data sources and data testing are also introduced in Section 3. The empirical results are discussed in Section 4. Finally, a brief conclusion and policy suggestions are arranged in Section 5.

2. Influencing Factors Analysisof Carbon Emission

The study on the influencing factors of carbon emission has gained close attention in recent years. Considerable research shows that carbon emission can be determined by many factors, such as the total population, age structure, aging, urbanization, income level, etc. [12–15]. However, there still exist disagreements due to the complicated mechanism of how these factorsaffecting carbon emission.

Firstly, the total population, the age structure, or both, has been found closely related to the carbon emission. For example, by analyzing the population age structure and carbon emission of Gansu province in China, Wang and Liu (2014) revealed that the proportion of the active labor force was the most significant influencing factor of the greenhouse gas emission, where 1% growth of the proportion of the active labor force caused 2.25% increase of the greenhouse gas emission [16]. The inter-relationship between population growth and GDP growth may be the oldest topic in macroeconomics. A complexity is that causality can run both ways. The demographic change affects GDP growth in China [17,18], and GDP growth has an obvious potential impact on carbon emission. GDP growth (or expected GDP growth) could impact the demographics through fertility rates and internal migration patterns. Lugauer et al. (2014) found that the age distribution had impact on carbon dioxide emissions from 1990 to 2006 by exploiting demographic variation in a panel of 46 countries [19]. Ma et al. (2013) used instrument variables to control the panel data's endogeneity and combined the static and dynamic panel data model to analyze the relationship of age structure and the scale of population on carbon dioxide emission in China, indicating that population size and age structure are two main factors driving the increment of carbon dioxide emission. The elasticity of population size on CO_2 emissions is 0.726 and that of the proportion of working age population is 0.017 [20]. Many more tools and data sources were used to verify this relationship. Qu and Jiang (2012) applied the expanded STIRPAT model to study the relationshipsamongChina's population size, agestructure and greenhouse gas (CO_2) emission with the panel data of 30 provinces in China, and showed that the growth of population size promoted the increase of greenhouse gas (CO_2) emission. People of different age groups influence the carbon emission intwo ways: production and consumption. Bigger active labor forces produce more carbon emission [21]. A similar conclusion was also drawn in Zagheni's work (2011), who found a stable relationship between the amount of carbon emission and age factor.

Growth of young and middle-aged group would increase the carbon emission [22]. Duan et al. (2012) used the extended STIRPAT model and ridge regression method to study the impact of total population and age structure on greenhouse gas emission in Japan from 1960 to 2007. The results indicated that the growth of population increased greenhouse gas emission. The elasticities of the proportion of working age population on carbon emission in the stages of rapid industrialization, industrial structure upgrading and economic depression are 0.1045, 0.3876 and 0.0820, respectively. Hence, the impact of age factor on greenhouse gas emission is non-trivial [23]. Zhu and Peng (2012) used the ridge regression to explore the relationships among total population, age and greenhouse gas emission and found that the impact of age factor is beyond that of total population on carbon emission [24]. However, an opposite conclusion was given by Liddle et al. (2010): the ratio of people 34–64 years old would inhibit the increase of carbon emission by analyzing 17 developed countries from 1960 to 2005 [25]. The working age dependent rate on carbon emission showing stable negative impacts in both the long runand short runwas also observedbyZhou and Wang (2015) [26].

In addition, population aging is considered as one of the most prominent influencing factors of carbon emission. Li (2015) analyzed the relationship between population aging and carbon emission by applying provincial dynamic panel data in China from 1995 to 2012. The impact of aging on carbon emission presented an inverted U-shaped curve: at the early stage, the growth of aging population increased carbon emission, but it in turn helped to reduce carbon emission in the long term [27]. On the contrary, Wang and Zhou (2011) discovereda U-shaped relationship between the aging and greenhouse gas emissionwhen theyused the Kaya model to study population size, aging and greenhouse gas emission with the panel data of ninecountries from 1961 to 2010 [28]. At the early stage, aging was beneficial to reduce carbon emission for the physical deterioration and the decrease of consumption, however, at the later stage, elderly people needed more medical andnurse demands, thus increasing the carbon emission. Currently, opinions on the impact of aging population on the carbon emission remain inconsistent, and how the aging population influences the carbon emission is still inconclusive. Research wouldcontribute tothe clear understanding of the relationship between population aging and carbon emission in China. In this paper, we focus on the aging factor on the carbon emission, and propose a new extended STIRPAT model to analyze the impact of population aging on the carbon emission in China.

Moreover, there exist many other factors related to the carbon emission, e.g., urbanization, income level, energy consumption intensity, and industrial structure. Xu et al. (2018), Zhang et al. (2017), and Zhao et al. (2015) found that urbanization had a significant impact on energy consumption and carbon emissions [29–31]. Fan et al. (2006) studied how the income level and age structure influencecarbon emission, showing that the proportion of active labor force (15–64 years) in total population inhibited the increase of carbon emission in high-income countries during1975–2005 [32]. High energy consumption intensity indicates a high price or cost of converting energy into GDP, whereas low energy consumption intensity indicates a lower price or cost of converting energy into GDP.Besides, the proportion of the secondary industry output value of GDP, indicated by the industrial structure, can lead to a large amount of carbon emission.

3. Materials and Methods

3.1. The Model

IPAT model (Ehrlish and Holdren, 1971) was introduced to assess the population pressure on the environment [33]. It has been widely used to quantitatively evaluate the effects of population growth on the increase of carbon emission. Researchers assessed the impact of population on the carbon emission by altering the population size while keeping other variables constant (Zhu and Peng, 2012) [24].

In the IPAT model, the main driving forces behind the environmental impact (I) are population (P), affluence (A) and technology (T), i.e.,

$$I = f(P, A, T) \tag{1}$$

where I represents the environmental pressure (impact), P denotes the population size (population), A denotes affluence, and T stands for technology. A simple form of this model is $I = P \times A \times T$, consisting of the product of population, affluence, and technology. However, the simple model can only be used to measure the constant proportional impacts of the independent variables on the dependent variable. In reality, the influencing mechanism on the environment quality is very complex. The impact of these factors on the environment quality is often non-monotonic, so the IPAT model does not effectively reflect the relationship between the environmental quality and its influencing factors.

To overcome the limitations of the IPAT model, Dietz and Rosa (1994) put forward a STIRPAT model [34]. In this model, the population, affluence and technology nonlinearly impact on the quality of the environment, reflecting the influence of human factors on the quality of the environment. The STIRPAT model is typically given by:

$$I = aP^b A^c T^d e \tag{2}$$

where a, b, c, and d are the (exponent) coefficients of the STIRPAT model. e is the error term. Obviously, when $a = b = c = d = e = 1$, the STIRPAT model is reduced to the IPAT model. To estimate the parameters a, b, c, and d by sample data, we next take the natural logarithm on both sides of Equation (2), and then the model turns into an additive regression model:

$$\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e \tag{3}$$

To quantitatively measure the effects of aging on the carbon emission in China, we extend the STIRPAT model in this paper. We suppose that the carbon emission is still closely related to the population, affluence and technology. Further, the population can be divided into three variables, i.e., the aging rate (the proportion of the elderly people), population size and urbanization rate. The urbanization rate as a controlled variable, although rarely studied, also plays a crucial role in the carbon emission. Per capita consumption is used to measure the affluence, and the energy consumption intensity is used to measure the technical level.

The extended STIRPAT model is given as follows (Model 4):

$$\ln C_{it} = a + b_1 \ln P_{it} + b_2 \ln old_{it} + \mathrm{b}_3 \ln ur_{it} + c \ln A_{it} + d \ln \mathrm{en}_{it} + f \mathrm{lnerchan}_{it} + e_{it} \tag{4}$$

If the squared old_{it} is introduced in Model 4, we can get the following Model 5:

$$\begin{aligned} \ln C_{it} &= a + b_1 \ln P_{it} + b_2 \ln old_{it} + b_3 \mathrm{lnur} + b_4 (\ln old_{it})^2 + c \ln A_{it} + d \ln \mathrm{en}_{it} \\ &+ f \ln \mathrm{erchan}_{it} + e_{it} \end{aligned} \tag{5}$$

Here, i and t represent the region i and year t, so the dependent variable C_{it} represents the amount of carbon emission (million tons) at region i at year t. The coefficients of the independent variables a, b_1, b_2, b_3, c, d, and f can be estimated from the sample data. The explanatory variables are the influencing factors of carbon emission, as analyzed in Section 2. P_{it} stands for total population (10,000 persons), old_{it} denotes the aging rate of the population over 65 years old, and the control variable ur_{it} represents the urbanization rate. A_{it} stands for household consumption level (thousand RMB Yuan/person), and en_{it} stands for the energy consumption intensity (tons of standard coal/1000). Another controlled variable, $erchan_{it}$ represents the industrial structure (the proportion of the secondary industry output value of GDP), as it is also a big contributor to the carbon emission. e_{it} represents the error term. Except for the explanatory variable in Equation (4), there may exist other factors that influence the carbon emission. In the IPCCapproach ("identify calculation") [35,36], $C_{\text{fossil}} = D_{\text{fossil}} \times V \times H \times O$, where C_{fossil} represents the CO_2 emissions from fossil fuel combustion, D_{fossil} is the amount of energy consumption, V is the net calorific value, H is the carbon content, and O is the oxygenation. The oxygenation efficiency plays a vital role in the "identify calculation" of the carbon emission, and it is also an important influencing factor of the carbon emission in the "modeling process" (e.g., Equation (4)) [37]. A fact in econometrics is that, if the explanatory variables are purely independent, the loss of one explanatory variable would not change the regression coefficients of other variables. The oxygenation efficiency, although it can have significant influence on the carbon emission, is independent of the aging factor, and therefore, we do not include it in Equation (4).

3.2. Data Source

The dataset of 30 provinces in China (except for Hong Kong, Macao, Taiwan and Tibet) from 1999 to 2014 are analyzed here. Since a complete and unified CO_2 measurement system has not yet been established in China, many researchers use the various established source energy consumption to estimate the amount of CO_2 emission. Here, we use the terminal energy consumption to estimate the amount of carbon emission. The data of eight types of energy consumption released in the China energy statistical yearbook, including the coal, diesel, gasoline, kerosene, kerosene, fuel oil, coke and natural gas consumption, are selected in this paper. The carbon emission from these eight types of energy consumption are estimated by the standard coal coefficients and the carbon emission coefficients released by IPCC. It is given by:

$$C = \sum_i C_i = \sum_i \alpha_i f_i e_i \tag{6}$$

C represents the total carbon emission, and C_i represents the carbon emission by consuming type i of energy. α_i denotes the standard coal coefficients, f_i denotes the carbon emission coefficients, and e_i represents the total consumption of energy type i. The carbon emission coefficients of various energy sources and the specific coal coefficients are listed in Table 1.

Table 1. Standard coal coefficients and carbon emission coefficients of various energy sources.

Energy Type	Standard Coal Coefficient (kg Standard Coal)	Carbon Emission Coefficient (t Carbon/tce)
Coal (kg)	0.7143	0.7467
Diesel (kg)	1.4571	0.5913
Gasoline (kg)	1.4714	0.5532
Kerosene (kg)	1.4714	0.3416
Crude oil (kg)	1.4286	0.5854
Fuel oil (kg)	1.4286	0.6176
Coke (kg)	0.9714	0.1128
Natural gas (m^3)	1.3300	0.4479

Source: "China Energy Statistical Yearbook" and "IPCC national greenhouse gas inventory guide" (2006).

The data of the population, per capita consumption and the second industry output value are selected from "New China 60 Years Statistics Compilation" and "China Statistical Yearbook". To eliminate the inflationary effects, the per capita consumption is adjusted by the same price index in 1999.

3.3. Model Test

In the empirical analysis, spurious regressions may occur if we take several time series for regression analysis directly, for some kinds of time series especially economic time series often have the same changing tendency, but in fact they are irrelevant and these series are non-stationary. To avoid the occurrence of spurious regressions, the stationary test is essential. The LLC test and Fisher-ADF test are applied on each panel data. Table 2 shows the results of the stationary tests. All the variables of the first-order differential are stable and they are subject to I (1). Then we use Kao test to conduct the cointegration test (see Table 3). The results show that the variables are cointegrated, indicating that there is a long-term stable cointegration relationship between the carbon emission and the factors of population aging, urbanization rate, population size, per capita consumption, energy consumption intensity and industrial structure in China.

Table 2. Panel unit root test results.

Region	Variable	LLC Test	ADF-Fisher Test	1st Difference	LLC Test	Fisher-ADFTest
Nation	LnC	−2.27 (0.01)	29.27 (1.0)	$d$lnC	−15.33 (0.00)	232.90 (0.00)
	ln$P$	−2.99 (0.00)	92.52 (0.00)	$d$ln$P$	−43.23 (0.00)	339.65 (0.00)
	ln$A$	4.30 (1.00)	2.86 (1.00)	$d$ln$A$	−16.88 (0.00)	167.63 (0.00)
	lnold	−6.50 (0.00)	74.79 (0.09)	$d$lnold	−20.99 (0.00)	341.65 (0.00)
	(lnold)^2	−7.02 (0.00)	80.32 (0.04)	d(lnold)^2	−21.45 (0.00)	349.81 (0.00)
	lnen	3.34 (1.00)	10.17 (1.00)	$d$lnen	−13.73 (0.00)	222.20 (1.00)
	ln$erchan$	−3.61 (0.00)	50.56 (0.80)	$d$ln$erchan$	−9.0 (0.00)	143.66 (0.00)
	lnur	−6.08 (0.00)	86.11 (0.02)	$d$lnur	−43.48 (0.00)	284.97 (0.00)
	old	−4.96 (0.00)	66.57 (0.26)	d(old)	−18.73 (0.00)	316.79 (0.00)
	old^2	−3.48 (0.00)	58.67 (0.57)	d(old)^2	−17.40 (0.00)	307.94 (0.00)
east	ln$C$	−3.91 (0.00)	15.64 (0.90)	$d$lnC	−9.69 (0.00)	92.93 (0.00)
	ln$P$	−1.24 (0.11)	20.99 (0.64)	$d$lnP	−41.96 (0.00)	157.06 (0.00)
	ln$A$	2.72 (0.99)	0.86 (1.00)	$d$ln$A$	−12.31 (0.00)	120.37 (0.00)
	lnold	−3.61 (0.00)	39.40 (0.02)	d(old)	−11.63 (0.00)	122.43 (0.00)
	lnen	2.10 (0.98)	4.28 (1.00)	$d$lnen	−9.05 (0.00)	94.28 (0.00)
	ln$erchan$	−1.66 (0.05)	18.65 (0.77)	$d$ln$erchan$	−5.31 (0.00)	55.50 (0.00)
	lnur	−2.04 (0.02)	14.17 (0.94)	$d$lnur	−12.97 (0.00)	115.18 (0.00)
Centre	ln$C$	−0.19 (0.42)	3.86 (0.99)	$d$ln$C$	−7.51 (0.00)	58.11 (0.00)
	ln$P$	−4.82 (0.00)	56.98 (0.00)	$d$ln$P$	−39.81 (0.00)	107.37 (0.00)
	ln$A$	1.25 (0.89)	1.60 (1.00)	$d$ln$A$	−8.83 (0.00)	79.05 (0.00)
	lnold	−3.12 (0.00)	16.38 (0.57)	d(old)	−11.99 (0.00)	107.18 (0.00)
	lnen	3.30 (0.99)	0.38 (1.00)	$d$lnen	−6.90 (0.00)	63.26 (0.00)
	ln$erchan$	−1.56 (0.06)	10.80 (0.90)	$d$ln$erchan$	−3.75 (0.00)	32.66 (0.01)
	lnur	−5.44 (0.00)	30.09 (0.04)	$d$lnur	−12.81 (0.00)	89.31 (0.00)
West	ln$C$	0.31 (0.62)	9.77 (0.94)	$d$ln$C$	−9.18 (0.00)	81.86 (0.00)
	ln$P$	−0.19 (0.43)	14.55 (0.69)	$d$ln$P$	−5.28 (0.00)	75.21 (0.00)
	ln$A$	3.76 (0.99)	0.39 (1.00)	$d$ln$A$	−7.34 (0.00)	68.21 (0.00)
	lnold	−4.61 (0.00)	19.01 (0.39)	d(old)	−12.85 (0.00)	112.01 (0.00)
	lnen	0.26 (0.60)	5.51 (0.99)	$d$lnen	−7.42 (0.00)	64.66 (0.00)
	ln$erchan$	−3.28 (0.00)	21.11 (0.27)	$d$ln$erchan$	−6.23 (0.00)	55.49 (0.00)
	lnur	−2.98 (0.00)	41.85 (0.00)	$d$lnur	−39.62 (0.00)	80.48 (0.00)

Note: The number in parentheses is p value.

Table 3. Panel co-integration test results.

	Nation		East	Centre	West
	Model 4	**Model 5**	**Model 4**	**Model 4**	**Model 4**
ADF p value	−7.49 *** (0.00)	−7.69 *** (0.00)	−6.31 *** (0.00)	−4.22 *** (0.00)	−4.26 *** (0.00)

Note: *** indicates that the test value is significant at 10%, 5% and 1%.

As a prerequisite, the Hausman test is taken to determine the form of the model. Results of the Hausman test show that the random effects model is optimal, whereas heteroscedasticity and auto-correlations are found in the panel data. Therefore, the modified Wald test methodis applied to estimate the parameters based on the difference estimation. The test results show that there exist auto-correlations and heteroscedasticity among groups in the random effects model of each region at 1% significant level. To solve this problem, the feasible generalized least squares method (FGLS) is used to estimate the parameters of the random effects model.

3.4. Model Estimation

Models 4 and 5 are constructed at the national level to observe the impact of population aging, population size, urbanization rate, per capita consumption, energy consumption intensity and industrial structure on the carbon emission in China (Table 4). In Table 4, the latter three columns are the estimated results for regions of eastern, central and western, respectively. In Table 4, all the explanatory variables in each model are significant at the level of 1%.

Table 4. Estimation results.

	Model 4	Model 5	Eastern	Central	Western
Constant	−11.114 *** (−105.84)	−12.128 *** (−74.96)	−11.684 *** (−93.91)	−14.022 *** (−35.87)	−14.679 *** (−68.10)
$\ln old_{it}$	0.171 *** (16.68)	−0.738 *** (−6.36)	0.411 *** (25.06)	−0.285 *** (−6.33)	−0.207 *** (−5.86)
$(\ln old_{it})^2$		−0.183 *** (−7.72)			
$\ln P_{it}$	0.941 *** (230.74)	0.934 *** (181.72)	0.896 *** (168.12)	0.909 *** (60.52)	0.948 *** (75.50)
$\ln u_{it}$	0.619 *** (57.33)	0.625 *** (63.74)	0.149 *** (10.28)	0.419 *** (14.55)	0.396 *** (7.23)
$\ln A_{it}$	1.184 *** (155.38)	1.179 *** (159.26)	1.301 *** (168.12)	1.379 *** (63.66)	1.436 *** (83.46)
$\ln en_{it}$	1.013 *** (162.59)	1.016 *** (188.04)	1.066 *** (176.33)	1.071 *** (85.86)	1.036 *** (53.66)
$\ln erchan_{it}$	0.569 *** (83.35)	0.574 *** (50.68)	0.493 *** (48.91)	0.552 *** (14.44)	0.773 *** (16.83)
n	480	480	192	144	144
Hausman test p value	0.13	0.29	0.48	0.65	0.21
Heteroscedasticity test	0.00	0.00	0.00	0.00	0.00
Serial correlation test	0.00	0.00	0.00	0.00	0.00
Estimation method	FGLS	FGLS	FGLS	FGLS	FGLS
R^2	0.925	0.924	0.960	0.957	0.952

Note: *** indicate that the test value is significant at 10%, 5% and 1%. The number in parentheses is t test value.

4. Results and Discussion

4.1. Results and Discussion about Models for China

The coefficient of the population aging is positive in Model 4, indicating that aging can promote the increase of the carbon emission in China. The coefficients of other variables in Model 4 are all positive, which illustrates that the population size, urbanization rate, household consumption level, energy consumption intensity and the growing proportion of secondary industry value all have positive impacts on the carbon emission. Among all the variables, the regression coefficient of the household consumption level hasthe highest value of 1.184, indicating that the carbon emission would increase by 1.184% when the household consumption level has 1% growth. The elasticities of the energy consumption intensity and population size are 1.013 and 0.941, respectively, meaning that 1% growth of the energy consumption intensity makes the carbon emission increase by 1.013% and 1% growth of the population size brings 0.941% increase of the carbon emission. Moreover, the population aging, the proportion of secondary industry value and urbanization rate own the smallest impact coefficients, 0.171, 0.569 and 0.619, respectively, which shows that, with 1% growth of the population aging rate, the proportion of secondary industry value and urbanization rate will increase the carbon emission by 0.171%, 0.569% and 0.619%, respectively.

The population is the main driving factor of the carbon emission in China. Because of China's huge population base, people's daily production and consumption will bring enormous energy consumption, thus promoting the increase of the carbon emission. Nowadays, China is experiencing a fast-changing process of the age structure of population, in which the aging process accelerates the growth of the elderly population, who gradually lose their labor abilities and become pure consumers. With the increasing consumption level and the elderly's gradually changing consumption structure, the demand of the medical care, travelling, housing, etc., except for the basic consumption of four, clothes, etc. becomes much higher, leading to the increase of life using energy consumption, thus increasing the carbon emission in the population aging process. With population aging, the increasing demand from the elderly population has brought enormous industrial demand. Products and services of the aging industries emerging account for a greater and greater share in the national economy. Hence, the aging industry will become the new space of China's economic growth. To develop low carbon and sustainable aging industry is necessary for China.To take a low carbon life will be necessary for individual's choice especially for old people.

Energy consumption intensity is an important measuring indicator of the level of production and technology in the process of industrialization. The higher energy consumption intensity is, the lower the technical level is. Therefore, by advancing the level of production and technology, energy intensity per GDP will be lessened, much energy will be saved and more carbon emission will be reduced in the industrialization process. For the population aging on the one hand, a fact is that the decrease of birthrate and the aggravation of the aging society make the average age of working population increase, which hinders the flow of the active labor force from traditional energy-intensive industries to new high-tech and service industries. Besides, population aging may cause a shortage of creative young labor force and hamper the development and advancing of technology in the process of industrialization, further aggravate the burden of carbon emissions in China. On the other hand, rapid development of urbanization impels more and more rural population to move to cities and towns. However, most of these transfer labor forces finally enter the high pollution and high energy-consuming industrial sectors due to the backward tertiary industry, thus promoting the increase of China's carbon emissions.

The coefficient of the square of population aging is negative in Model 5, indicating that there exists a significant inverted U-shaped curve relationship between the population aging and carbon emission. Figure 1 also shows that there is a significant inverted U-shaped relationship between the population aging and carbon emission. The result is similar toLi's (2015) conclusion [27]. The results show that the relationship between population aging and carbon emission is rather complex. Table 4 shows that the impact of population aging on the carbon emission in China is significantly different by regions. The impact of population aging on the carbon emission in the eastern region is positive with the coefficient of 0.411, while that in the middle and western regions are negative with the coefficients of -0.285 and -0.207, respectively. Compared to the estimated results for the whole nation in Model 4, only the impact of population aging on the carbon emission in the eastern region shows the same direction with that of the whole nation. It can be explained as below. High concentrations of people live in the eastern region, where the amount of elderly population is nearly equal to the sum of elderly population in the central and western regions, and the level of income and consumption of the aged people in the eastern region is much higher than those in the central and western regions. Therefore, integrating across the whole country, the impact of population aging on the carbon emission is positive but smaller than that in the eastern region.

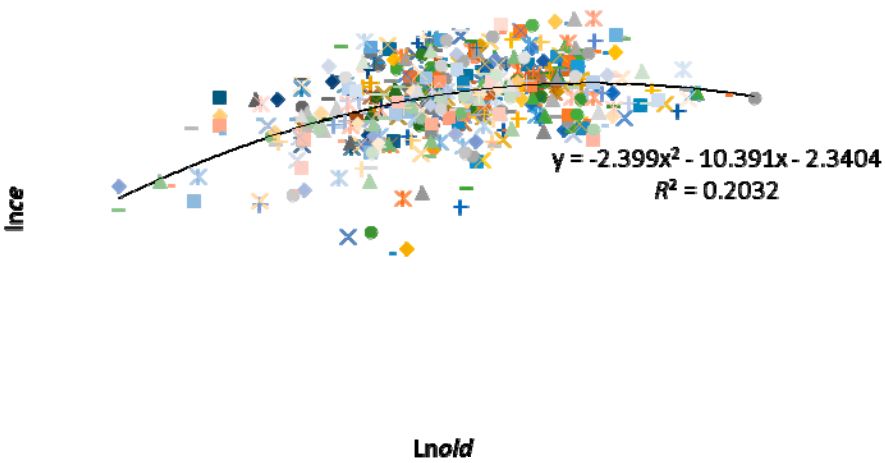

Figure 1. The relationship of carbon emission (ln*ce*) and population aging (ln*old*).

4.2. Results and Discussion about Models for Different Regions

Population aging is an objective rule accompanied by the economic and social development. In general, the level of population aging is positively correlated to the level of economic development, that is, more developed regions have higher levels of aging. China is a country with a vast territory and disequilibria of regional economic growth, which makes aging phenomenon significantly different in different regions. Due to the discrepancies of the economic structure, consumption structure and physical condition of the elder in different regions, the impact of population aging on the carbon emission in different regions are likely to vary.

For the eastern region, the effects of aging on the carbon emission is positive, which is the same as the regression results of the whole nation. As pure consumers, elder people's consumption demand has become increasingly high as their physical functions gradually decline. According to China report of the development on silver industry (2014), with the steady growth of economy and the gradually-perfected social pension insurance system from 2014 to 2050 in China, the consumption potential of the aged people will increase from 4 trillion to 106 trillion, accounting for 33% of GDP, increased from25% [6]. It predicts that with population aging and urbanization developing rapidly, China will face the growth peak of consumption potential of the aged people after the "twelfth five-year" or 2022. On the one hand, elderly people's demand of medical care and longevity increase gradually. York (2006) pointed out that aging people's demand in heating, transportation, electricity and other energy intensive products is far greater than other age groups [38]. On the other hand, under the traditional family values, Chinese parents often spend a lot of money on their children, such as the house and car purchase. Studies have shown that the aged population who own houses accounts for about 75% of the total number of the elderly. It is predicted that, by 2020, there will be more and more families who own two or more houses as the urbanization develops more and more rapidly. All these will increase the carbon emission.

For the central and western regions, the population aging will inhibit the carbon emission. As pure consumers, the elderly's consumption propensity is affected by the income level, social security level, health status and other factors. Since the reform and opening, the economic development has exhibited significant regional differences and the economic development in the central and western regions is far behind the eastern region, leading to the income discrepancy of the elderly in different regions. The "China Statistical Yearbook 2017" showed that, in 2016, per capita disposable income of urban residents in the eastern region was 39,650 RMB, and per capita disposable income of residents in the rural areas is 15,500 RMB. In the central and western regions, the numbers are 28,880 and 11,790, and 28,610 and 9.920, respectively. Per capita disposable income of the urban residents in the mid-west is only about 72% of that in the eastern region, and per capita disposable income of rural residents is only about 70% of that in the eastern region. Therefore, the level of per capita income in the central and western regions is far less than that in the eastern region either in urban or rural areas.

From the perspective of insurance, great differences exist in different regions about the insurance coverage of the elderly. According to China's labor and Social Security Yearbook 2015, the number of people participating in the basic old-age insurance and medical insurance in Guangdong, Jiangsu, Zhejiang, Shandong, Liaoning, Beijing and Shanghai is the highest, while in western region such as Guizhou, Gansu, Qinghai, Xinjiang and other areas, it is the lowest. Population in the eastern region accounts for 45% of the total population, but the number of people participating in the basic old-age insurance and medical insurance accounts for 63% and 55%, respectively. Population in the central region accounts for 33% of the total population, and the number of insured accounts for 23% and 26%. Population in the western region accounts for 22% of the total population, and the number of insured accounts for 14% and 19%. Hence, the proportion of the insured people in eastern region is much higher than the proportion of its population, while in the central and western regions the social security insurance rate is far behind the proportion of their population. From the viewpoint of the elderly's physical condition, discrepancies also significantly exist in different regions. Du and Wang (2013) pointed out that the health status of elder people in the mid-west region is significantly lower than that of the eastern region [39]. The income level and social insurance rate of the aged in the mid-west region are also much lower than those in the eastern region. All these directly restrict the elderly's propensity to consume, thus decreasing their consumption level. To guarantee their basic living conditions and the medical costs, elderly people in western region will usually compression some unnecessary spending such as transportation, housing and other products with high energy consumption. Affected by the economic conditions, consumption environment, degree of openness and the traditional values, propensity of the elder's in the mid-west to consume is lower than that of the eastern region. Therefore, the carbon emission driven by consumption is much lower and population aging will inhibit the carbon emission in the mid-west region.

From the angle of the influence coefficients, the estimated impact coefficient of the population aging on the carbon emission is −0.285 in the central region, indicating that 1% growth of the aging rate makes the carbon emission decrease by 0.285%. In the western region, the coefficient is −0.207, meaning that 1% growth of the aging rate leads to 0.207% reduction of the carbon emission, less than that in the central region. It can be explained by two aspects. On the one hand, the statistical yearbook showed that the elderly population in the central region is larger than that in the western region in 2014, the elderly population in the central and western regions were 43.93 million and 31.72 million, respectively, while the elderly population in the eastern region is 1.38 times of that in the western region. On the other hand, population aging can promote the upgrading of the industrial structure in the central region, as concluded by Nie and Huang (2015) [40]. They applied the panel data of the 31 provinces from 2003 to 2013 in China to study the impact of population ageing on the upgrading of the industrial structure and found that population aging in the central region would promote the upgrading of the local industrial structure compared to the western region. Enterprises in traditional labor-intensive industries in the central region are facing the dilemma of rising labor price because of the shortage of active labor force caused by aging. They have to transform to capital- and technology-intensive ones to escape from the dilemma, thus upgrading the local industrial structure. However, although enterprises in the western region are restrained by the same problem, the economy there is still mainly driven by the labor-intensive industries. It is difficult to transfer the capital- and technology-intensive industries to the west region due to the imperfect infrastructure in the western region. Research of Li and Fu (2010) also showed that development of the western region would still be dominated by labor-intensive industries in the near future [41].

5. Conclusions

In this paper, we propose an expanded STIRPAT model and use the panel co-integration method to analyze the relationship between the population aging and the carbon emission with the panel data of 30 provinces in China from 1999 to 2014. It is found that there exists a significant inverted U-shape curve relationship between population aging and carbon emission, and regional discrepancies exist in the impact of population aging on the carbon emission. The effect of population aging on the carbon emission in the eastern region is positive, while, in the mid-west, it is negative. The population size, urbanization rate, household consumption level, energy consumption intensity and the growing proportion of secondary industry value all have positive significant impacts on the carbon emission in China. The regression coefficient of the household consumption level owes the highest value, indicating that household consumption levelis the most important factor of carbon emission.

China is currently in the process of population aging. The gradual disappearance of the demographic dividend brought by population aging, the decrease of the proportion of the active labor force and the present situation that economic growth relies mainly on traditional labor- and energy-intensive industries, impel China to find a new low-carbon economic growth mode for the coordinate development between population aging and low-carbon economy under the background of aging population. According to the analysis above, we give several suggestions as follows:

(1) Develop the aging industry dominated by third industry as a new source of economic growth. With population aging, the increasing demand from the elderly population has brought enormous industrial demand. Products and services of the aging industries emerging account for a greater and greater share in the national economy. The rapid growth of the elder population will be a social norm in the future and there will be a huge development space for the aging industry. Hence, the aging industry will become the new wellspring of China's economic growth.

(2) Change the current consumption patterns and advocate low carbon consumption. Promoting low carbon consumption is the common responsibility of the whole society and it needs the joint efforts of individuals, enterprises and government. For individuals, they should reduce the carbon emission by setting up low carbon concept and living a low carbon life, such as using energy-saving lamps, public transport. By innovating and advancing technologies and actively developing low-carbon and recyclable materials, enterprises can save energy and reduce carbon emission during the production process and achieve the low carbonization and ecologicalization of the production value chain. As to the government, efforts can be made by formulating relevant policies and regulations to restrain the high-carbon behavior of the enterprise. Meanwhile, policies and regulations of encouraging the low carbon production should also be made and put into practice to mobilize enterprises' research and development initiative.

(3) Continuously encourage procreation to slow down the rapid growth of the aging rate. Full liberalization of the two-child policy was determined on the fifth Plenary Session of the 18th CPC Central Committee and fully implemented since 1 January 2016. This policy will fundamentally solve the aging problem caused by the low fertility rate in China. However, although the second child is allowed by the policy, if the corresponding supporting welfare does not keep up with the pace, parents may hesitate to have a second child because of the heavy living burden and the high cost of raising children. Therefore, it is necessary for the government to learn experiences on promoting the two-child policy from South Korea, Russia, Japan and some other countries. Some policies or active measures such ashonorary awards, tax cuts, maternity protection, etc. should be implemented to alleviate family's burden.

(4) Improve the social security system for the elderly in the middle-west regions. Compared to the eastern region, the coverage of social security of the elderly is still very limited in the central and western regions in China. The income level, endowment insurance and basic medical insurance rate of the old people in the mid-west regions are significantly lower than those of the aged in the eastern region. Therefore, the nation should strengthen the endowment support in the mid-west and provide some certain welfare policies for people in the central and western regions.

In addition to the influencing factors considered in this paper, other factors with respect to the carbon emission, for instance pollution offshoring, abatement, and clear environmental policy [42,43], can be further discussed in future.

Author Contributions: Conceptualization, W.L.; Methodology, W.L.; Software, X.Q.; Validation, X.Z. and W.L.; Formal Analysis, X.Z.; Data Curation, X.Q.; Writing—Original Draft Preparation, W.L.; and Writing—Review and Editing, X.Z.

Funding: This research was funded by China National Key Research and Development Plan (2016YFC07018).

Acknowledgments: The authors would like to thank for four anonymous reviewers for their valuable comments and suggestions that helped improve the quality of the manuscript.

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

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