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Original Research Article

Research and Countermeasures Analysis on the Impact of Population Aging on Carbon Emissions in China

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Abstract: Based on the improved STIRPAT model and the affiliation function assessment method, this paper explores the relationship between population aging degrees and carbon emissions in China, divides the population aging into two groups of tendency aging and complete aging for regression investigation, and further explores the impact at the national and regional levels. The results show that, firstly, at the national level, population aging in China has an inhibitory effect on carbon emissions at the present stage. Secondly, at the degree of aging, the effects are different, among which tendency aging can negatively affect carbon emissions, while complete aging is positively affecting carbon emissions, and in the long term, the relationship shows an inverted "U" shape. Thirdly, at the regional level, there are obvious regional differences in these effects. This study helps the government to improve the relevant coping strategies for an aging society.

Keywords: Population aging, Carbon emissions, STIRPAT model, Affiliation functions.

INTRODUCTION

Data from the International Energy Agency (IEA) suggests that total global carbon dioxide emissions in 2021 have increased by 6% year on year to 36.3 billion tons, with the recovery of the world economy after the COVID-19 and its heavy dependence on coal. Among them, China's CO2 emissions alone have exceeded 11.9 billion tons and ranking first in the world, so how to seek sustainable development in economic development and ecological protection has become one of the most pressing issues of this century. Against this background, China aims to have carbon dioxide emissions peak before 2030 and achieve carbon neutrality before 2060 and officially launched the carbon emissions trading system, actively responding to the Paris Agreement and promoting a global green and low-carbon transition (Hao *et al.*, 2022). According to the Sixth Assessment Report of the IPCC, human factors have had an unprecedented and irreversible impact on global carbon emissions; therefore, in order to achieve the "dual carbon" target, it is important to explore the impact of changes in age structure on carbon emissions in China. Among the many factors, the influence of population aging should not be underestimated. With many countries around the world stepping into the aging society one after another (Byass, 2008), the relationship between this emerging factor and carbon emissions has been gradually discussed by scholars. However, in the current situation in China, there is still a lack of consensus on this relationship. Additionally, considering the increasing degree of global aging in the last decade, scholars should pay more attention to whether different degrees of population aging directly affect carbon emissions, while some studies usually analyze aging as a part of the demographic factors or as a secondary factor affecting other major factors (Tarazkar, 2021).

And China has the characteristics of vast territory and a large population, so it is indispensable to explore regional differences. This paper is different from most related studies in four aspects. First, it introduces an affiliation function to weight and quantify the population aging trend, so as to make it more in line with the actual situation of contemporary Chinese society. Second, the population aging trend is classified into tendency aging (population aged 50-64) and complete aging (population aged 65 and above), in which the dynamic process is treated statically and further research is carried out.

Third, population aging is examined as a direct factor affecting carbon emissions. Fourth, according to the economy, we divide all the provinces into eastern, central, western and northeastern regions, and choose a province in each region as a regional representative to study whether there are differences between regions. Based on this, this paper aims to find out the relationship between different aging degrees and carbon emissions in China, and to explore how this relationship varies among different regions. Nowadays, with the aim of coordinated development of the economy and environment, this relationship should be rationally utilized to promote sustainable economic development while ensuring the needs of the elderly for the aged, so as to construct a green economic system in which the economy and the environment are in harmonious symbiosis.

Literature and hypothesis

Current impacts of aging

Previous studies have not yet reached a consensus on the relationship between aging and the environment due to different research approaches and scopes. Some scholars build predictive models based on some relevant data from the past and argue that there is a negative relationship between aging and carbon emissions (Dalton *et al.*, 2008). Other scholars draw the same conclusion from empirical studies of panel data from multiple regions or countries, and point out that the magnitude of this effect increases with the degree of aging (Kim *et al.*, 2020; Wang & Li, 2021). It is because at the social level, carbon emissions are essentially determined by production and consumption activities, and changes in the age structure will, to a certain extent, lead to changes in social behavioral patterns. In other words, the impact of aging on the environment is mainly affected by production and consumption. (Tian *et al.*, 2015). From the production perspective, the increasing aging will cause a serious shortage of labor, hindering the development of industrial economy and indirectly reducing the use of fossil energy (Cylus & Tayara, 2021).

From the consumption perspective, studies have shown that older people's willingness to consume and their ability to consume for survival, development and enjoyment have all decreased. Firstly, with the growth of age and the stabilization of living conditions, the purchasing power of the elderly for their own bulk goods gradually declined, and the level of consumption was also reduced (Ho & Shirahada, 2020). And due to the popularization and improvement of the pension security system and changes in the division of labor in the family, most of the expenditures of the elderly are shared by society and children (Liu & Sun, 2015); secondly, the consumption demand of the elderly for learning professional skills, taking qualification exams and other education and training, and transportation and travel, etc., is greatly reduced after retirement (Liu, 2021); besides, aggravation in aging will make the consumption demand for leisure, recreation, tourism, and culture continuously decline, thus reducing the energy consumption generated by activities outside the home (Prskawetz *et al.*, 2004). According to the above analysis, aging of current population in China has negative impacts on carbon emissions. Based on this, this paper puts forward the following hypothesis:

H1: China’s current population aging level is conducive to reducing carbon emissions.

Comparative impacts of different aging degrees

Considering that the elderly at different age stages have different behavioral characteristics (Hansen *et al.*, 2016), according to Lindh and Malmberg (1999), combined with China's retirement age and WHO age division standards, population aging is divided into two stages: tendency aging and complete aging. Among them, tendency aging refers to the transitional stage of the middle-aged and old-aged groups aged between 50-64, and complete aging refers to the elderly group aged 65 and above. Comparative analysis of these two different age groups shows that the group that is tendency aging is in a relatively stable stage of work and family life, usually accompanied by an increase in the rate of savings to meet a higher quality of retirement life and inheritance gifts, so that the reduction of the desire to consume within this stage plays a significant part in reducing carbon emissions (Song & Zhang, 2018). While the complete aging stage is full of many unstable factors, the need to meet a variety of needs, including the planning and construction of convenient service facilities for the elderly, the treatment of diseases of the elderly and daily health care, as well as the funeral industry, which will ultimately promote the rise of carbon emissions by stimulating production and consumption (Fung *et al.*, 2022). This is also consistent with the analysis made by some scholars on the basis of STIRPAT model (Liu *et al.*, 2022). Thus, we formulate the following hypothesis:

H2: The current stage of tendency aging is conducive to carbon emission reduction, while complete aging is the opposite.

Long-term impacts of aging

Research shows that the early stage of aging is often accompanied by the relative accumulation of labor capital, which means that economic development is accompanied by an increase in fossil energy consumption; however, the further deepening of complete aging will lead to complete derailment between the elderly and the economy and society, and in the long run, is usually accompanied by the aggravation of low fertility and shrinking of the population size. Therefore, if the population aging phenomenon is not reasonably controlled, it will lead to an insufficient labor supply in the market and slow down the accumulation of social capital, which can finally achieve the effect of reducing the consumption of fossil energy. Consequently, the relationship between population aging and carbon emission is inverted "U" shape (Zhang & Tan, 2016; Li *et al.*, 2018; Balsalobre-Lorente *et al.*, 2021). Based on this, we put forward the following hypothesis:

H3: The effect of complete aging on carbon emissions is an inverted "U" shape in the long run.

Data and Methods

Sample collection and data source

In this paper, China's national and provincial data from 2009-2018 are selected as research samples based on the availability of the data. These data are mainly from the National Bureau of Statistics and provincial statistical bureaus (Shan *et al.*, 2018; Shan *et al.*, 2020; Guan *et al.*, 2021).

Variables and measurements

Dependent variable

In this paper, we choose the value of total apparent carbon emissions (COEM) to measure the environmental load, which is the level of carbon emissions, and use the statistical data characterization of the "China Apparent Carbon Emission Inventory".

Independent variable

Here independent variables are DAG, DTAG and DCAG.

(1) Degree of population aging (DAG). Considering that the level of aging should not be directly divided by age figures, this paper introduces the "affiliation function", which takes the value from the interval [0, 1] to describe the degree to which an element belongs to the fuzzy set. We use the assignment method to construct the affiliation function as follows:

$$A(x) = \begin{cases} 0 & , \quad x \in [0,49] \\ \frac{x-50}{15} & , \quad x \in [50,64] \\ 1 & , \quad x \in [65,\infty) \end{cases} \qquad (1)$$

Here x stands for age and $A(x)$ for the degree of affiliation of different ages to the concept of " aging".

Therefore, we construct the following formula to characterize the level of population aging:

$$DAG = \sum_{x=0}^{\infty} r_x \times A(x) \qquad (2)$$

Here r_x is the proportion of the population aged x to the total population of the region in that year.

(2) Degree of tendency aging (DTAG). According to Lindh and Malmberg (1999), this paper selects the proportion of China's population aged 50-64 to characterize the degree of tendency aging.

(3) Degree of complete aging (DCAG). Similarly, according to Lindh and Malmberg (1999), the proportion of population aged 65 and above in China is selected to represent the degree of complete aging.

Control variable

According to Quan *et al.*, (2020), this paper selects POPS, PGDP, COIN and SENC as control variables to be studied. Various variables are shown in Table 1 below.

Table 1: Various variables

Variable attribute	Variable	Definition
Dependent variable	COEM	The value of total apparent carbon emissions
Independent variable	DAG	Weighted sum of population shares by age 50 and above
	DTAG	Share of population aged 50 to 64
	DCAG	Share of population aged 65 and above
Control variable	POPS	Total household registered population
	PGDP	Per capita GDP
	COIN	Carbon emissions per unit of GDP
	SENC	Share of coal consumption

The model

Ehrlich and Holdren (1971) designed a quantitative IPAT model that can be widely used to study environmental impact factors, then Dietz and Rosa (1994) introduced the exponential form so that it can be used to analyze the nonlinear problems on the environment, and established an improved form of the old model, that is, STIRPAT model. Based on this, firstly, in order to verify the negative relationship at this stage (H1), this paper constructs the following improved STIRPAT model I:

$$\ln COEM = \zeta_0 + \zeta_1(\ln DAG) + dControl + e \qquad (3)$$

Second, in order to verify the different effects of two different degrees of aging (H2), the variables DTAG and DCAG were introduced respectively, and the following models II and III were obtained:

$$\ln COEM = \alpha_0 + \alpha_1(\ln DTAG) + dControl + e \quad (4)$$

$$\ln COEM = \beta_0 + \beta_1(\ln DCAG) + dControl + e \quad (5)$$

Finally, the following model IV is used to verify the existence of an inverted "U" shaped relationship (H3):

$$\ln COEM = \eta_0 + \eta_1(\ln DCAG) + \eta_2(\ln DCAG)^2 + dControl + e \quad (6)$$

Where $\ln COEM$ represents the environmental load, that is, carbon emission level; $\zeta_0,\ \alpha_0,\ \beta_0,\ and\ \eta_0$ are intercept terms; $\zeta_1,\ \alpha_1,\ \beta_1,\ \eta_1\ and\ \eta_2$ are regression coefficients; $Control$ is the control variables; d is the control variables coefficient and e represents the stochastic disturbance term.

EMPIRICAL EVIDENCE

Correlation analysis

Considering that there may be a linear correlation between two or more explanatory variables in the above four models, we conduct covariance tests for the variables before formally starting the regression so as to avoid the impact of multicollinearity on the empirical results. The results show that the maximum variance inflation factor (VIF) of the five explanatory variables in model I is 1791.85, and the average variance inflation factor is 797.22, which are all much larger than 10. Similarly, the average variance inflation factor of model II is 661.38, that of model III is 468.38, and that of model IV is 106222.37, which are all much larger than 10. This indicates that all four models have serious multicollinearity and cannot be used directly for parameter estimation using ordinary least squares. While all the explanatory variables in the model set up above could not be excluded or replaced, this paper chose to use ridge regression for fitting. Ridge regression is a modified algorithm based on least squares estimation, in which a principal diagonal matrix is introduced into the standardized matrix to make the parameter estimates have less variance, resulting in a more realistic regression equation (Hoerl & Kennard, 2000).

Ridge regression results

Table 2 shows the results of ridge regression of the four models. According to model I, the regression coefficient is -2.10, which means that the deepening of aging degree in China at this stage has negatively effects on carbon emissions (p=0.01). Also, according to model II and III, the regression coefficients are -1.59 and 1.14 respectively, which means that the degree of tendency aging negatively affects carbon emissions (p=0.05), while the degree of complete aging positively affects carbon emissions (p=0.01). In addition, according to the model IV in the following table, it can be confirmed that the relationship between the two is an inverted "U" shape in the long run (p=0.05). In a word, hypotheses H1, H2 and H3 are all confirmed.

Table 2: The Ridge regression results

Variables	**Model I**	**Model II**	**Model III**	**Model IV**
	$\ln COEM$	**$\ln COEM$**	**$\ln COEM$**	**$\ln COEM$**
$\ln DAG$	-2.10***			
$\ln DTAG$		-1.59**		
$\ln DCAG$			1.14***	1.14***
$(\ln DCAG)^2$				-2.83**
$Control$	√	√	√	√

Note: "*" p< 0.1; "**" p< 0.05; and "***" p< 0.01.

Regional variability test

According to the four major economic regions, this paper divides China's provinces into four regions, and selects one province with representative population in each region to conduct ridge regression analysis to verify the regional differences of the conclusions (Beijing, Henan, Chongqing, and Heilongjiang for example). The results are shown in the following four tables. From Table 3 we can see that: population aging, tendency aging and complete aging in the eastern region are all positively affecting carbon emissions, in which the regression coefficient of population aging is 2.64 (p=0.01), which is obviously a more significant test result.

Table 3: The results of eastern region

Variables	Eastern Region		
	Model I	Model II	Model III
	$\ln COEM$	$\ln COEM$	$\ln COEM$
$\ln DAG$	2.64***		
$\ln DTAG$		2.42**	
$\ln DCAG$			2.52*
$Control$	√	√	√

Note: "*" p< 0.1; "**" p< 0.05; and "***" p< 0.01.

From Table 4 we can see that different aging degrees in the central region also positively affect carbon emissions (p=0.01).

Table 4: The results of central region

Variables	Central Region		
	Model I	Model II	Model III
	$\ln COEM$	$\ln COEM$	$\ln COEM$
$\ln DAG$	4.36***		
$\ln DTAG$		3.65***	
$\ln DCAG$			4.20***
$Control$	√	√	√

Note: "*" p< 0.1; "**" p< 0.05; and "***" p< 0.01.

As can be seen from Table 5, population aging level and degree of complete aging in the western region both have a positive impact on carbon emissions, while degree of tendency aging significantly inhibits this process (p=0.01).

Table 5: The results of western region

Variables	Western Region		
	Model I	Model II	Model III
	$\ln COEM$	$\ln COEM$	$\ln COEM$
$\ln DAG$	2.81**		
$\ln DTAG$		-6.24***	
$\ln DCAG$			6.29***
$Control$	√	√	√

Note: "*" p< 0.1; "**" p< 0.05; and "***" p< 0.01.

From Table 6 we can see that population aging level and degree of complete aging in the western region both affect carbon emissions negatively, while degree of tendency aging significantly positively affects this process (p=0.01), which is exactly the opposite of the results for the western region

Table 6: The results of northeastern region

Variables	Northeastern Region		
	Model I	Model II	Model III
	$\ln COEM$	$\ln COEM$	$\ln COEM$
$\ln DAG$	-0.94***		
$\ln DTAG$		2.11***	
$\ln DCAG$			-1.47***
$Control$	√	√	√

Note: "*" p< 0.1; "**" p< 0.05; and "***" p< 0.01.

DISCUSSION

Conclusions

This paper aims to explore the relationship between population aging and the environment in China by extending the traditional STIRPAT model and using data from the country and four representative provinces from 2009 to 2018 as research samples. The main conclusions are as follows:

1. At the current stage, the population aging level of Chinese society negatively affects carbon emissions.
2. Different degrees of aging have different effects. At present, China's tendency aging has a negative impact on

carbon emissions, while complete aging has a positive impact. However, in the long run, the relationship will show an inverted "U" shape.

3. There are obvious regional differences in these relationships, among which the difference is most pronounced between the northeast and the west, which may be due to the imbalance in economic development over the long term.

Insights

After exploring some of the impacts of the population on the environment, this study has the following implications for how the government can promote further economic development in an aging society: (1) From the perspective of ensuring the material needs of the middle-aged and the elderly and improving their quality of life: On the one hand, it is compelling to further improve the medical insurance system for the elderly with regard to major illnesses, to narrow the urban-rural gap, and to set up a medical insurance system in which commercial insurance and social insurance are mutually supportive. On the other hand, it is necessary to expand the scale of social pensions and to raise the level of social pensions. Vigorous efforts should be made towards the development of short- or long-term leisure and recreational activities with local characteristics to satisfy the social needs of the elderly, such as gate ball courts for the elderly, chess and card rooms for the elderly and theater clubs for the elderly. Reducing the energy consumption of the elderly in their daily lives while stimulating consumer demand, thereby promoting sustainable economic and social development.

(2) From the perspective of meeting the spiritual needs of the middle-aged and the elderly and promoting their comprehensive development: On the one hand, with the progress of science and technology and the development of the economy, the average life expectancy is increasing year by year, and public policies should adopt a more flexible positioning of the role of the elderly in society. Therefore, it is urgent to improve the flexible retirement system in accordance with the health level of the elderly in different regions, and to encourage the middle-aged and elderly to choose their retirement age flexibly. On the other hand, an industrial system suitable for the employment of the middle-aged and the elderly should be explored and improved, and the middle-aged and the elderly should be encouraged to keep abreast of the times, to learn specialized knowledge and to seek re-employment that suits them and their environment. And we should also help the middle-aged and the elderly to create social wealth while strengthening their personal value and sense of belonging to society, so that the active aging of society can be promoted and realized (Guido *et al.,* 2022).

Contributions

Our study adds the perspective of the transition stage of aging (tendency aging) to the current literature on the relationship between population aging and the ecological environment, clarifies that the relationship between different degrees of population aging and the environment varies markedly according to the time and region of development. It confirms the argument that the long-term development of aging population and carbon emissions will eventually show an inverted "U" shaped relationship as well (Zhang & Tan, 2016; Li *et al.,* 2018; Balsalobre-Lorente *et al.*, 2021). This will also help the government to formulate and improve the relevant pension measures to cope with the increasingly serious environmental problems, in accordance with the local conditions and the needs of each individual.

Limitations and Future Research

The limitation of this study is mainly the limited sample years. In future studies, the sample years can be further extended so the scope of the study can be expanded to exclude localization and chance and obtain more robust results. In addition, although the results are fully explained and justified by the empirical analysis in this paper, carbon emissions may still be affected by other factors (consumption structure, total number of households, average household size, etc.).

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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