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The Impact of Population Aging on Carbon Emissions: Based on the Perspective of Industrial Structure Upgrading and Rationalization

Xinran Li[1,a,*]

[1]*College of Economic and Management, Harbin Normal University, Harbin, China*
a. 3058849475@qq.com
**corresponding author*

Abstract: China's aging population society has entered a high-speed deepening stage, promoting energy saving and emission reduction, realizing low carbon development history is an important strategic task in our country. On the Basis of panel data since 2011 to 2021, using an intermediate effect model, this paper studies the relations among the population aging, industry structure upgrading as well as rationalization and the emission of carbon dioxide. The results indicate that aging exerts a significant positive impact on carbon emissions. The influence of population aging on carbon emissions is inverted U shape. When aging reaches a certain level, the influence on carbon emissions has a nonlinear feature of decreasing marginal effect. The aging can exert a prominent influence on carbon emissions in the regions through upgrading and rationalization of the industrial structure. That influence about population aging on carbon emissions is remarkable in the region. Therefore, promoting the optimization process of industry structure forced by population aging contributes to realizing "reduction effect of carbon emissions" under the background of population aging.

Keywords: population aging, industrial structure advanced, industrial structure rationalized, carbon emissions.

1. Introduction

The problem of aging population and the problem of environment and climate are two important problems facing our country. Entering the 21st century, Chinese population situation has changed greatly. Since China stepped into an aging society in 2000, Chinese population is aging more and more. At present, population aging has become the most distinctive feature of China's population structure. Data show that the total amount of Chinese people who are over 60 years old is about 264 million, contributing to 18.7 percent of country's total population. Among them, older people 65 years of age and older is as high as 190 million, accounting for 13.5%, which shows the severity of population aging. At the same time, with global warming, carbon emission has become one of the hot research areas. [1]

Aging and low carbon are the unity of mutual influence, and are two important factors to facilitate the green development of human society. The level of aging is an indispensable way to move towards low-carbon, and the low-carbon transition also needs to be based on the degree of aging, which will further make the industrial base tend to a higher level, rationalize the industrial chain, and push forward the industrial structure blossom. Therefore, under the international situation and background of deepening population aging level, accelerating the development as well as rationalization of industry structure, and tightening carbon emission constraints, so as to develop green transformation faster and better and realize the goal of "double carbon", this paper intends to examine the relation between population aging, industry structure upgrading, rationalization and carbon emissions to conduct empirical analysis.

2. Literature Review

Since the early 21st century, the world is seeing a rapid rise on carbon emissions. According to the global carbon emissions data released in 2023, the annual global carbon emissions in 2023 will be 35.78 billion tons, a rise of 0.11% by comparison with the same phase in 2022. Simultaneously, the problem of aging population has also become the focus of social attention, and China will be in a period of rapid deepening of aging in the next 30 years. At present, the development of Chinese economy which comes from high speed is changing into high quality, however, due to rapid economic growth, it will inevitably cause a certain degree of damage to the environment, in order to make up for this shortcoming as much as possible, one possible approach is the optimization of industry structure. At present, the study about carbon emissions focuses on population factors, economic development status and technology.

2.1. Impacts of population aging on carbon emissions

The aging of population stands for the phenomenon that the percentage of elder people (usually those more than 65 years old) in a country or region is gradually increasing, while the percentage of the young population (mainly those of childbearing age) is relatively decreasing. With social-economic development and changes in lifestyle, fertility rates have generally declined, resulting in a slowdown in the growth of the young population. At the same time, improvements in medical care and living standards have allowed people to live longer on average, further increasing the percentage of the elderly people.

From the existing research literature, most domestic scholars believe that population aging has a prominent positive effect[2][3][4][5] on carbon emissions. Based on panel data and dynamic spatial SDM model, Liu and Ma [6] concluded that population aging will directly promote carbon emissions. In addition, indirectly affect carbon emissions through intermediate variables about industry structure. Qi[7]pointed out that aging exerts a prominent active effect on emissions, that is, aging will accelerate the increase of carbon emissions, and there have considerable variations in its influences in diverse regions, and aging in the east will promote carbon emissions, while aging in the west will inhibit carbon emissions. However, some scholars convince that aging exerts a significant inactive influence[8][9][10][11][12] on carbon emissions. Li et al. [13]discussed the impact of aging on carbon emissions from the viewpoint of production from the perspective of total labor productivity. They found a nonlinear relation between aging and carbon emissions through the threshold panel effect, and concluded that aging exerts a prominent inhibitory influence on carbon emissions except in western region. Further, some scholars have researched the more complex relation between population aging and carbon emissions. In addition, believe having cyclical effects and U shape or inverted U shape relationships [14]. The influences of aging on carbon emissions are multifaceted, involving production, consumption and other levels, and the positive and negative effects are merged. In addition, there has a U shape on the degree of aging and emissions. In short order, with the rising percent of elder population, the labor market shrinks, the overall consumption power will decline, and the effective demand of the elderly population for related consumption will also decrease, which will restrain the summary carbon emissions in the course of manufacture as well as expenditure. In

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long run, the increase of the elderly population's expenditure on social insurance, public health and medical services will significantly promote carbon emissions[15][16]. According to Xu's [17] extended STIRPAT model based on FGLS estimation, aging has promotion as well as inhibition impacts on the carbon emissions and the promotion impact is greater than the inhibition impact. Through empirical analysis, it is found that there has an inverse U-shaped relation between aging and carbon emissions. At the initial phase of aging, the degree will increase the total emissions, but when it reaches to certainly level, will lay inhibitory influence on the total emissions.

2.2. The impact of industrial structure on carbon emissions

China's industry structure is generally separated into three categories: primary industry is basic industry with agriculture and forestry, secondary industry is main industry, and tertiary industry is called service industry. The so-called “optimization” of industry structure stands for an energetic activity of promoting rationalizations and advanced industrial structures.

In literatures similar to the subject studied in this paper, domestic and foreign scholars have also conducted a wealth of studies on the influence of optimizing industrial structure on carbon emissions. Chang [18] took forward and backward emission effects related to departmental input and output as an important basis for carbon emissions to play a role in industrial structure, and combined linkage analysis with multi-objective planning. It shows that so as to cut carbon dioxide emissions, China needs changing its industry structure. Yang and Deng [19] conducted an empirical measurement on the relation in industry structure upgrading and emissions, pointing out that industrial structure rationalization exerts a prominent inhibitory influence on the carbon emissions, and which influence of industry structure upgrading toward carbon emissions indicates a reversed "V" pattern, that is, the relationship between promoting as well as inhibiting industry structure first, but it is certain that industry structure upgrading has a significant impact on carbon emissions. Yan [20] built a theoretical model, taking Jiangsu, Zhejiang and Shanghai areas as an example, to explain the long term equilibrium relation in carbon emissions and industrial structure, in addition, it will make secondary industry a main factor to increase carbon emissions, in order to solve this situation, we must accelerate the upgrading in tertiary industry to neutralize carbon dioxide emissions. At present, some scholars have found and verified that industrial structure, an intermediate variable, will indirectly affect carbon emissions when analyzing the effect about aging on carbon emissions through an intermediary effect [21] model. Zhang et al. [22] adopted the panel threshold structure to conclude which has a non-linear relation in industrial structure change as well as carbon emission, and that the former has a threshold impact on green innovation.

In summary, by summarizing the conclusions of relevant scholars, it can be found that although there are many researches based on the pairwise relation among population aging, industry structure, carbon emission, here lacks full discussion about the interaction between three. On the basis of existing researches, we put the three ingredients about population aging, advanced industrial structure and rational industrial structure into a model, and makes use of provincial panel data to have a deep analysis on influence about population aging on the carbon emissions as well as nonlinear effects in this from a view of optimizing industrial structure.

3. Theoretical mechanism and research hypothesis

With a rapid development of aging, their consumption habits of older group may be more inclined to use traditional, less energy efficient products, rather than more energy-saving and environmentally friendly new products, so the consumption of goods as well as services about the older tends to be more energy-intensive, making these products and services cause more carbon emissions in the production process. In addition, with age, the elderly's demand for medical services-related aspects further increases, and the energy consumption of medical facilities and procedures is usually higher, which will also contribute to increase carbon emissions. Simultaneously, from a perspective on individual behavior of the older, as the elderly quit their jobs, social outings are greatly reduced, and the time spent living at home is increased, resulting in a significant increase in the operation time of appliances such as heating, water, electricity and lighting, which tend to have high energy consumption. In addition, the residential and service facilities designed for the elderly may pay more attention to comfort and convenience in the design and operation, while ignoring the environmental concept of low-carbon environmental protection, which may also lead to higher energy consumption, and keep an active role in promoting the carbon emissions increase. Therefore, hypothesis 1 is put forward in following paper.

H1: Population aging has a positive impact on carbon emissions.

In the early stage of population aging, a country or region may experience the so-called "demographic dividend", that is, a high proportion of working-age population, which usually promotes economic growth and industrialization process, but this stage may be accompanied by increasing energy use and carbon emissions. Simultaneously, consumption patterns at the beginning of aging tend to favor more energy-intensive lifestyles, such as housing, transportation and leisure activities, and thus significantly increase carbon emissions. However, when aging reaches a certain level, the proportion of working-age population begins to decline, and the growth of total population declines or even shows negative growth, which will lead to the decrease of overall consumption and production behavior, thus reducing energy demand and carbon emissions. Moreover, aging and urbanization tend to develop in parallel. In an early phase of urbanization, carbon emissions may rise as infrastructure construction and population concentration. But as urbanization matures, more efficient urban planning and public transport systems can reduce energy use and carbon emissions. Consequently, it will inhibit carbon emissions, and it will promote them more than it inhibits them. On the basis of above analysis, hypothesis 2 is put forward in following paper.

H2: The effect about population aging on carbon emissions shows a reversed U-shaped feature.

The influence about aging on carbon emissions is not only reflected at the direct level, but also exerts a great influence on carbon emissions by some intermediary effects. On one side, the population aging pressure may cause the imbalance between labor supply and demand, and change the structure of labor supply and demand. Under this case, low-skilled workers will take the initiative to accept relevant education and skill training in order to improve their competitive advantages, and the level of human capital will rise accordingly. Furthermore, having a high-level labor force tends to focus on forming the talent base for enterprise innovation, which in turn accumulates human capital for the development of related industries, and ultimately has an impact on industrial structure advancement as well as rationalization. On the flip side, the advancement and rationalization process about industry structure is often achieved by changes in proportion about various industrial sectors. With the rise of modern high-yield manufacturing, service and information industries, the number of traditional labor-intensive industries has been sharply reduced, and its cost advantage and profit margin have been squeezed. As a result, traditional industries have continuously increased the input of human capital and technology to improve productivity, which will indirectly affect carbon emissions. Based on this, hypothesis 3 is put forward in following paper.

H3: Population aging may accelerate the upgrading as well as rationalization of regional industrial structure and further influence carbon emissions.

China's population aging is in a deep development stage, but due to the different economic development level, energy structure and efficiency, population structure and consumption habits in different regions of China, there are significant differences in the degree of aging among cities, and the effect on carbon emissions are diverse as well. On the whole, the eastern region has a higher level of economic development, its industrial structure is dominated by service industry, high-tech industry and export-oriented economy, and its infrastructure is relatively perfect, and the level of urban modernization keeps comparatively high, followed by the middle and west regions. Compared to east regions, the lifestyle in elderly is quite different, and they may rely more on traditional energy sources, which will lead to more energy consumption, which may increase carbon emissions. On the basis of this, hypothesis 4 is put forward in following paper.

H4: The effect about aging on emissions has heterogeneity in diverse regions.

4. Model building and empirical analysis

4.1. Model setting

So as to demonstrate the relation in the aging of population, the upgrading and the rationalization of industrial structure and the carbon emissions, following paper constructs regression model.

$$\ln y_{it}=\alpha_0+\alpha_1 \; pa_{it}+\theta X_{it}+\varepsilon_{it} \tag{1}$$

Since the transmission mechanism of population aging is relatively complex and needs further research, based on model (1), the square term about population aging is indicated, as shown in (2).

$$\ln y_{it}=\alpha_0+\alpha_1 \; pa_{it}+\alpha_2 pa_{it}{}^2+\theta X_{it}+\varepsilon_{it} \tag{2}$$

$$IS_{it}=\beta_0+\beta_1 \; pa_{it} + \beta_2 pa_{it}{}^2+\theta X_{it}+\varepsilon_{it} \tag{3}$$

$$\ln y_{it}=\gamma_1+\gamma_2 \; pa_{it} + \gamma_3 pa_{it}{}^2+\gamma_4 IS_{it}+\theta X_{it}+\varepsilon_{it} \tag{4}$$

In the mode l, y represents the total carbon emissions, pa represents the population aging level, (IS represents industrial structure upgrading, which can be divided into TS and TL, TS is industrial structure upgrading, TL is industrial structure rationalization), X_{it} represents a series of control variables, i represents provinces, t represents years, α is an coefficient with estimation, ε_{it} represents the random error term.

4.2. Description of Variables

4.2.1. Explained Variables

The explained variable is carbon emission (CO2). With reference to Cong et al. [23], carbon emissions of each province in this paper = Range 1 emission + Range 2 emission + Range 3 emission. Coverage 1 covers all direct emissions in each province and jurisdictions, including GHG emissions from transport, construction, industry, agriculture, forestry and land which takes waste treatment activities. Coverage 2 covers indirect energy-related emissions that take place outside provincial jurisdictions and primarily include emissions generated by electricity, heating and/or refrigeration purchased to satisfy consumption within the province. Coverage 3 covers rest indirect emissions arising from provincial activities that occur outside the province's jurisdiction but are not covered by Coverage 2.

4.2.2. Core explanatory variables

(1) Population aging (pa). Referring to Zhao [24]'s calculation method, the percentage of the elderly aged 65 years or older is used as a measure.

(2) Upgrading of industrial structure

Review to the existing documents, we can find that main factors about the upgrading of industry structure are analyzed from two perspectives of industry structure upgrading and rationalization. This paper will follow the previous research methods.

For the measurement data of industry structure upgrading (TS), referring to Gan et al. [25]. In the paper, uses the percent of the output value of the tertiary industry to the secondary industry to measure TS. It may be seen that the percent keeps positively correlated with the upgrading of industrial structure; In addition, Theil index (TL) is selected as an indicator to measure the rationalization of industry structure, and the calculating formula is as follows:

$$\mathrm{TL}=f(x)=\sum_{n=1}^{n}\left(\frac{Y_i}{Y}\right)\ln\left(\frac{Y_i}{L_i}/\frac{Y}{L}\right)(\mathrm{i}=1,2,3) \tag{5}$$

Where TL represents the Thiel index, Y is the total provincial output, L is total employed, i represents industry, and n is industrial sections' amount. When economy keeps an equilibrium state, Theil index (TL) is 0. If Theil index (TL) is not 0, which means that the industry structure is out of balance, that is, industry structure is unreasonable.

4.2.3. Control variables

As the impacts of carbon emission are complex and diverse, it may cause large errors only from the point of view on population aging and upgrading and rationalization of the industry structure. Therefore, with reference to previous studies [26][27][28][29], the following variables are selected as control variables using at this paper to assure an accuracy and comprehensiveness of empirical analysis.

(1) Infrastructure construction (rail). In China, the main infrastructure is based on roads and railways, so for the calculation of infrastructure construction, this paper selects the percentage of the total of road as well as railway mileage of each provincial region in the area of each provincial administrative region to measure.

(2) Foreign direct Investment (fdi). In the paper, the percent of FDI to regional GDP is taken as natural logarithm.

(3) Population size (pop). In this paper, the natural logarithm of the annual total provincial population is used to measure.

4.2.4. Data sources and descriptive statistics

From what has been mentioned, the statistics of 31 Chinese provinces (Hong Kong, Macao, Taiwan are excluded) since 2011 to 2021 are selected. These statistics are primarily collected from China Statistical Yearbook, China Energy Statistical Yearbook and China Environmental Statistical Yearbook of different years, As indicated in Table 1. Chinese population aging is relatively high, and there are great differences among provinces and different years. The east, middle and west have great regional heterogeneity because of the influence about economic development stage and labor force quantity. In addition, there remains a huge gap between the rationalization of industry structure and foreign direct investment. High-quality foreign investments will push the transformation of industry structure to rationalize, but low foreign investment will be difficult to adapt to innovation in science as well as technology and industry developments, and have diverse impacts on the industry structure upgrading.

Table 1: Descriptive statistics of variables

Variables	Average	Standard Deviation	Minimum	Maximum
Ln(carbon)	5.641	0.571	4.161	6.465
pa	10.695	2.774	4.820	18.800
Ln(TS)	4.819	0.379	3.965	6.262
Ln(TL)	7.168	0.868	4.407	8.939
pasq	122.062	63.150	23.232	353.440

Table 1: (continued).

Ln(fdi)	7.081	1.281	0.872	9.401
rail	0.975	0.517	0.917	2.263
Ln(pop)	3.525	0.842	1.128	4.843

4.3. Empirical analysis

4.3.1. Regression of benchmark model

So as to ensure the strong balance of the research results, we use a method by gradually adding variables to carry out the benchmark regression, and related results are revealed in Table 2. Among them, column (1) is univariate regression about carbon emission on population aging; In column (2), the square term [30] of controlling variable aging is added; Column (3) further adds the control variable foreign direct investment level; Column (4) continue to add infrastructure construction as a control variable; And column (5) finally added population size as a control variable to form the final baseline regression model.

Table 2: Benchmark regression results

Explanatory variables	Ln (carbon)				
	(1)	(2)	(3)	(4)	(5)
pa	0.044*** (0.003)	0.043*** (0.004)	0.033*** (0.005)	0.034*** (0.005)	0.077** (0.023)
pasq					-0.002* (0.001)
Ln(fdi)		-0.005 (0.012)	-0.006 (0.012)	-0.008 (0.012)	-0.009 (0.012)
rail			0.291*** (0.076)	0.209** (0.087)	0.227** (0.087)
Ln(pop)				0.445* (0.237)	0.292 (0.249)
Constant term	5.170*** (0.038)	5.210*** (0.113)	5.043*** (0.119)	3.561*** (0.797)	3.844*** (0.808)
N	341	341	341	341	341
R^2	0.339	0.339	0.369	0.377	0.384

Note: ***, **, and * are significant at 1%, 5%, and 10% respectively, and are robust standard errors in parentheses. No further details will be done, and only core variables will be discussed, the same below.

The regression shows that with each control variable added continuously, the goodness of fit of the model continues to improve, while the population aging coefficient has remained prominent and changed little. Combined with the results in column (4), it can be seen that a 1% rise in population aging degree will cause a 0.034% rise on total carbon emissions, and hypothesis 1 is verified. On one side, population aging directly affects consumption pattern and demand structure. Increasing the elder people can lead to demand increase for services, such as health care and elderly care, the provision of which often requires a lot of energy and resources, thus increasing the carbon emissions. On the flip side, that consumption preferences of elderly people may prompt enterprises to increase the production of related products, further driving the growth of energy consumption as well as carbon emissions.

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As far as control variables, the development on infrastructure construction exerts a prominent active effect on carbon emission. According to the information between Zhejiang Transportation Science and Technology Information Resource Sharing Platform, highway infrastructure construction has a large input in material and energy consumption, and shows a wide influence on the ecosystem. At present, the total amount from China's transportation infrastructure construction ranks among the top in the world, which will inevitably bring high carbon emission intensity to a certain extent.

The variable pasq was further introduced into the model and the regression was carried out again. The results are given in Table 2, column (5). And results indicate that impacts of aging on carbon emissions presents a reversed U shape, that is, as the population grows older, its influence on carbon emissions increases first, then decreases. By conclusion, hypothesis 2 can be verified.

4.3.2. Robustness test

The method of stepwise regression is used to put into the benchmark regression, and the outcomes have been robust to a certain extent. Next, the validity of this research results is deeply tested through replace the explanatory variables. Specifically, the percentage of population who aged 65 years or older was taken as an alternative to the elderly dependency percentage for robustness test. The remaining variables, data sources and regression methods are the same as above, and results are revealed in the first column of Table 3. We may find from the results that the estimated coefficient of the main explanatory variable calculated by a new measurement method still remains significant, that is, the positive impact about aging on carbon emissions keeps significant as well, that in keeping with baseline regression conclusion and proves the validity which research concludes.

Moreover, due to Chinese vast territory, compared to other provinces, the four cities which have Central Government's direct management have relatively higher comprehensive development level and greater advantages in infrastructure construction. Therefore, the regression [31] is carried out after excluding the samples of Beijing, Tianjin, Shanghai and Chongqing. As it revealed on the second column of Table 3, there still remains a prominent active impact on emissions due to aging, which is in line with the expected conclusion.

Table 3: Robustness test

	Alternative measurement methods	Exclude municipalities
	Ln(carbon)	Ln(carbon)
pa	0.205***	0.035***
	(0.003)	(0.004)
Constant term	3.754***	3.707***
	(0.798)	(0.728)
Control variables	Control	
N	341	297
R^2	0.370	0.365

4.3.3. Intermediate effect test

Next, the intermediate industry structure upgrading and rationalization variables are added in order to carry out further regression, and whether the effects of two factors play a conductive role in population aging mechanism on carbon emissions is explored. The stepwise regression method is used to verify the mechanism, and relevant results are revealed at Table 4. Among them, column (1) is the benchmark regression result, which belongs to the first step of the three-step method of intermediate test; Columns (2) and (3) are the test results of the industrial structure upgrading of

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intermediate variables; Columns (4) and (5) are test results of the industrial structure rationalization of intermediate variables.

Table 4: Regression of intermediary effect

	Advance of industrial structure			Rationalization of industrial structure	
	(1) Ln(carbon)	(2) Ln(TS)	(3) Ln(carbon)	(4) Ln(TL)	(5) Ln(carbon)
pa	0.077*** (0.023)	0.172*** (0.025)	0.056** (0.025)	-0.309*** (0.050)	0.063** (0.025)
Ln(TS)			0.125** (0.052)		
Ln(TL)					-0.046* (0.027)
pasq	-0.002* (0.001)	-0.004*** (0.001)	-0.001 (0.001)	0.008*** (0.002)	-0.001 (0.001)
Ln(fdi)	-0.009 (0.012)	0.010 (0.013)	-0.010 (0.012)	-0.005 (0.026)	-0.009 (0.012)
rail	0.227** (0.087)	0.389*** (0.095)	0.178** (0.089)	-0.481** (0.186)	0.205** (0.088)
Ln(pop)	0.292 (0.249)	-0.280 (0.272)	0.327 (0.248)	-2.734*** (0.531)	0.166 (0.259)
Constant term	3.844*** (0.808)	4.047*** (0.881)	3.337*** (0.829)	19.581*** (1.722)	4.749*** (0.961)
N	341	341	341	341	341
R^2	0.384	0.610	0.395	0.583	0.390

On the one hand, the aging of population exerts a prominent positive influence on the industry structure upgrading, and the industry structure upgrading also exerts a prominent active influence on carbon emission, that is, the higher aging of population is, the more industry structure develops, and the more emissions will be. Simultaneously, in keeping with the stepwise regression outcomes, the industrial structure upgrading plays a partial mediating role in population aging's impact on carbon emissions, and the ratio about intermediary effect to the total effect is 0.279, indicating that about 27.9% of influences about population aging on carbon emissions are realized through intermediary effect on the industrial structure upgrading. A possible explanation is that with the increase of older people, the consumption needs of older people are also increasing, and the diversification between consumption demand of the elderly group and the quality penetration of the consumption concept will further refine the social division of labor, thus promote the third industry to develop further, that is, accelerating the process of industrial structure upgrading. The third industry contains many energy-intensive industries, which require a large amount of energy supply, so the carbon emissions will be increased.

On the flip hand, population aging exerts a prominent negative influence on industrial structure rationalization, and industrial structure rationalization also exerts a prominent negative influence on carbon emissions. That is, the higher degree population aging has, the weaker level industrial structure rationalization will have, and thus cause carbon emissions decrease. Simultaneously, we may find from the stepwise regression outcomes that industry structure also plays parts of mediating effect on the population aging process impacting carbon emissions, and the ratio about mediating effect to the

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total effect is 0.185, indicating that about 18.5% of the influences about aging on carbon emissions are realized through mediating effect of industry structure rationalization. A possible explanation is that with the increasing aging degree of old people, the number of working-age people will decline, and then the supply of labor force will also decrease. It is difficult to promote the science and technology they have mastered, which will inhibit the development of labor-intensive industries, that is to say, it is disadvantageous to the industrial structure rationalization process, and carbon emissions will decrease accordingly. In summary, hypothesis 3 can be verified.

5. Heterogeneity analysis

Because of the difference in the level of development in different regions, the level of aging in diverse regions has obvious heterogeneity. In this paper, based on the regional division method [32] of relevant scholars in China, 31 provincial administrative regions in research object are separated into three regions: east, middle and west regions, and hypothesis 1 is verified by constructing a fixed-effect model. The results of regression are presented at Table 5. The results indicate that: for east region, the population aging coefficient is 0.026, and the significance test passes 1%, that is to say, for every 1% increase, the regional carbon emissions will increase by 2.6%. As for the middle and west regions, the aging coefficient is active and both significance test passes 1%, but it is significantly higher than the eastern region. This is probably because the fact that the elderly population in east region has a higher living standard, more consumption and increased carbon emissions, but the elder people in the middle and west region relies more on fossil fuels for heating, so active influences on carbon emissions are more obvious under conditions of a deeper degree of population aging.

Table 5: Analysis of regional heterogeneity

	Ln(carbon)		
	(1) Eastern	(2) Middle	(3) Western
pa	0.026*** (0.004)	0.420*** (0.010)	0.046*** (0.015)
Control variables	Control		
Constant term	4.670*** (0.338)	4.859*** (1.216)	3.762*** (0.538)
N	341	341	341
R^2	0.666	0.445	0.247

In summary, as to east, middle and west regions, aging will have a positive impact on carbon emissions, but its impact is stronger in middle and west regions. Hypothesis 1 and hypothesis 4 are tested.

6. Conclusions and recommendations

6.1. Research Conclusions

Under the background of deepening aging, the degree about population aging and industrial structure upgrading and rationalization are major factors that impact carbon emissions. Based on the view of upgrading and rationalization, how to reduce carbon emissions with the help of population aging is an important topic that needs to be studied at present. On the basis of the panel statistic of various provinces since 2011 to 2021, this paper studies the relationship between population aging, industrial structure upgrading as well as rationalization and carbon emission, safely draws the conclusions:

As the primary element, population aging exerts a positive promoting effect on carbon emissions, which is prominently active at 1% stage. Second, the effect about population aging on carbon emissions presents a reversed U shape. At the beginning of aging, the increase in carbon emissions will be obvious. Conversely, the influence of aging will be weakened when the aging level reaches certainly level. Third, population aging will further affect carbon emissions by the industrial structure upgrading and rationalization. The rapid development about tertiary industries such as the aging industry and the service industry promotes industry structure upgrading process, and increase consuming energy will exert a positive effect on carbon emissions. With the continuous upgrading and adjustment of industrial institutions, the industrial structure will become more rational, and the carbon emissions will be correspondingly reduced. Fourth, the effect about aging on emissions has heterogeneity in regions. Because of the relatively underdeveloped economy as well as the low acceptance about clean energy use in middle and west regions, the effect on regional carbon emissions is more obvious.

6.2. Suggestions

On the Basis of empirical test results in this paper, the subsequent policy suggestions are proposed:

First, strengthen the innovation incentive mechanism of low-carbon technology, gradually enhance the development and use of green technology by the elderly, decline the consumption and utilization efficiency of energy while ensuring original or even higher economic benefits, and deeply implement the integration concept of low-carbon development.

Second, we should grasp the opportunities brought about by the aging of the population and take a holistic view of its impact. Population aging brings opportunities and challenges to economy and society. Although it will cause the rise of carbon emissions in the initial stage, it will promote the improvement of carbon emission performance to a certain extent, thus contributing to the achievement of China's double carbon target. Due to a continuous existence of demographic dividend, we can reduce the consumption of energy and carbon emissions of elder people can be further reduced, so that we can raise the urbanization level, decline the total carbon emissions, and achieve sustainable economic growth and social sustainable development.

Third, under the background of an aging population, we should promote the adjustment about the structure of industries suitable for aging and promote their optimization and upgrading. Different strategies should be adopted in line with the characteristics of different industries. For the rapidly developing elderly service industry, it is necessary to further implement the low-carbon production ideas, formulate and carry out effective regional energy saving and emission reductions policies, and ensure that carbon emissions are suppressed from the source.

Fourth, we should fully understand the differences in regional development and strengthen regional cooperation. For some economically underdeveloped areas in middle and west regions, infrastructure construction should be further improved, and certain capital and technical support should be provided to accelerate developments of related industries. For the economically developed eastern regions, measures should be taken to enhance their innovation capacity, vigorously develop regional advantages, and enhance the integrated development of different regions.

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