AIMS Mathematics, 8(5): 10468–10485.
DOI: 10.3934/math.2023531
Received: 10 January 2023
Revised: 20 February 2023
Accepted: 21 February 2023
Published: 01 March 2023

http://www.aimspress.com/journal/Math

Research article

The impact of population aging on economic growth: a case study on China

Yue Liu[1,*], Liming Chen[2,*], Liangting Lv[3] and Pierre Failler[4]

[1] Business School, Hunan Institute of Technology, Hengyang 421000, China
[2] School of Finance and Statistics, Hunan University, Changsha 410079, China
[3] Party School of the CPC Beihai Municipal Committee, Beihai 536002, China
[4] Economics and Finance Group, Portsmouth Business School, University of Portsmouth, Portsmouth PO1 3DE, UK

* **Correspondence:** Email: liuyue2013@hnu.edu.cn, chenliming@hnu.edu.cn.

Abstract: The impact of population aging on economic growth is a very important issue in the process of population structure change. This paper first proposes research hypotheses based on a systematic literature review and theoretical analysis of the negative and positive effects of population aging on economic growth. Then, based on the data of 30 provinces in the Chinese Mainland from 2000 to 2019, this paper empirically tests the impact of population aging on economic growth and its impact mechanism using a static panel data model, a dynamic panel data model and a mediating effect model. Our empirical analysis leads to the following conclusions. First, population aging has a significant inhibitory effect on economic growth. Second, the industrial structure upgrading plays a mediating role in the process of population aging affecting economic growth; that is, population aging inhibits economic growth by affecting the overall upgrading of the industrial structure as well as the industrial rationalization and optimization. Last, some policy implications are proposed based on the research conclusions.

Keywords: population aging; economic growth; heterogeneous effect
Mathematics Subject Classification: 62J05

1. Introduction

The population is the fundamental labor production factor and an essential resource for economic growth. As the labor provider of production factors, the population plays a critical role in economic development. While engaging in social production, human beings also act as consumers and play an essential role in economic growth through consumption. Therefore, population and economic growth are interrelated with each other. Population not only affects economic development in terms of the total amount but also significantly impacts the economy in terms of population structure. Since the 21st century, the population aging issue has become one of the greatest challenges for humans, profoundly impacting various fields, especially the economy. In the 1870s, some Western European countries, represented by France, entered the aging society. In the 20th century, especially after World War II, a growing number of developed countries accelerated the process of entering the senior community. By studying the influence of population age structure on economic growth, the age structure of the young population can effectively promote economic growth.

China's population structure has undergone significant changes in recent decades due to the influence of many factors, such as the family planning policy, rapid urbanization, and changes in fertility intention in industrialization. China has entered a stage of rapid population aging, which is more complicated than in developed countries, severely impacting economic growth. Therefore, taking the impact of China's aging population on economic growth as a case study can help us comprehensively grasp the public policies and measures to deal with the aging trend and related problems in practice in developing countries, ensuring sustainable and healthy operation of the national economy.

Despite multi-dimensional discussions and studies on how population aging affects economic growth, the direction of the impact of population aging on economic growth remains clear. The relevant literature is roughly divided into the following two categories.

Research of the first category holds that population aging has a negative effect on economic growth. Euijune et al. constructed the Computable General Equilibrium (CGE) population model and found that the aging population would lead to the decline of the total economy [1]. Scholars like Lancia and Prarolof found that after reaching a certain age threshold, the ability of individuals to learn new knowledge and new technology and their innovation ability decreases with the growth of age, which has a negative effect on scientific and technological innovation [2–5]. Some scholars analyzed the impact of population aging in some Asian countries on their economies, and they found that aging would reduce the savings rate of households, governments, and countries, affect the material capital of economic development, and then have a negative impact on economic development [6–9]. Gonzalez-Eiras & Niepelt argued that an aging population would increase the social security and public expenditures of the medical system, crowding out government investment expenditure on education, which would not be conducive to the accumulation of human capital [10,11]. Some Chinese researchers found that in the key period of economic transformation to the high-quality, the increasing of the aging degree has accelerated the disappearance of the "first demographic dividend", and the increasing pension burden has expanded the financial burden of the government, ultimately hindering economic growth; meanwhile, it is pointed out that the "second demographic dividend" can be stimulated by establishing a compatible pension insurance system [12–14]. Zhao Liqin and Han Zanyong constructed a dynamic panel model for empirical

analysis based on the economic growth theory, and the empirical results show that aging has a negative impact on the economic aggregate through the impact of technological progress and human capital accumulation [15]. Gong Feng, Wang Zhao and Yu Jinliang constructed the Overlapping Generations (OLG) model and found that the intensification of population aging would be detrimental to the balance of public welfare expenditure, thus exacerbating the intergenerational fiscal imbalance and making the fiscal expenditure structure unbalanced [16].

Research of the second category posits that population aging has uncertain effects on economic growth. Fougere et al. revised the OLG model to analyze the long-term impact of population aging on labor supply and human capital accumulation, and they found that the deepening of aging reduced labor supply, but at the same time, the mature experience and skills accumulated by middle-aged labor can improve labor productivity, and the extension of average life expectancy can prompt young people to increase investment in human capital [17]. Some studies analyzed the influence path of population aging on economic growth and found that population aging had a positive human capital effect on economic growth [18–20]. Some scholars focused on the mediating effect of the labor force participation rate and labor productivity, showing that aging can promote the improvement of labor productivity and thus increase the economic growth rate, but it can also reduce the labor participation rate and thus have a negative effect on economic growth [21–23]. At the same time, some researchers focused on labor supply and innovation as the impact paths. Their findings showed that aging does not have a significant negative impact on economic growth at present because it can force scientific and technological innovation, thus indirectly promoting economic growth, and the promoting effect is greater than the inhibiting effect through the path of the labor force in the short run. However, in the long run, with the continuous intensification of aging, the negative labor force effect will become increasingly severe, eventually inhibiting economic growth [24–27].

This study has a strong research foundation due to the abundance of literature on the impact of population aging on economic growth are abundant. However, there is still much to be explored in terms of quantitative analysis of the influence of population aging on economic growth and the impact mechanism. The main marginal contributions of this research are as follows. Firstly, this paper analyzes the effect of population aging on economic growth from both dynamic and static perspectives, which is rarely explored in existing research. Secondly, this study explores the impact mechanism of population aging on economic growth through the mediating variables of industrial structure upgrading, including the overall upgrading of industrial structure, the advancement of industrial structure, and the rationalization of industrial structure.

The structure of this article is as follows. The second section presents the theoretical analysis and research hypotheses on the impact of population aging on economic growth. Section three describes the model setting and variable measurement, as well as explains relevant data sources. The fourth section tests the impact of population aging on economic growth and analyzes the results. The fifth section draws the conclusions and proposes some policy implications.

2. Theoretical analysis and research hypothesis

2.1. Analysis of the impact of population aging on economic growth

Population development goes through various stages that significantly impact economic growth, which is mainly derived from the theory of demographic transition. The theory of demographic

transition explicitly explores the major transformation of population reproduction mode when the socio-economic level goes through the development process from low to high [27,28]. Generally speaking, the population change of an economy must go through three stages. The first stage is the traditional original stage. People blindly pursue survival without any control over the reproduction of offspring. The level of productivity is relatively low, and material resources are extremely scarce, forming a "high-high-low" population reproduction state. The second stage is the intermediate transition period, when society tends to be stable. The level of productivity is improved. Material resources are more abundant. The country generally restricts births, reducing the death and birth rates. The third stage is the modern stage. The strength of science and technology has been significantly enhanced. The level of productivity has been dramatically improved, and the national economy has developed rapidly. People's living standards have made a qualitative leap, and people's childbearing attitudes have begun to change, so the birth rate has gradually decreased, thus forming the "three low" model. Different stages of population transition have various but significant effects on economic growth, and the impact of the population structure at different stages on the economy also presents other characteristics.

In the process of population structure transformation, labor supply, human capital and scientific and technological innovation indirectly affect economic growth. First of all, since labor is the core supply factor of social production activities, aging impacts the labor supply market for the following two reasons. On the one hand, the intensification of aging can lead to the reduction of the supply of social labor. On the other hand, aging has an impact on the labor force participation rate, which means the existence of the disability risk of the elderly population, leading to an increase in the young people's burden of supporting the elderly and producing a "crowding out effect" on their labor supply time, thus reducing the labor participation rate in society. Secondly, population aging affects human capital, which is an important supply factor for economic development and an important basis for promoting economic growth. Population aging affects the investment in education at both the individual and social levels, which is the basis for accumulating human capital. Therefore, population aging will affect the accumulation level of human capital.

In addition, population aging inhibits economic growth by impacting scientific and technological innovation, which is a new driving force for economic growth and quality. From the individual level, the elderly labor force will inevitably have a gradual decline in physical function and learning ability, resulting in a decline in individual innovation enthusiasm and ability, which is not conducive to scientific and technological innovation. From the perspective of enterprises, the increase in the proportion of elderly employees will lead to the decline of the overall human capital level, and at the same time, expenses like the pension that the enterprise needs to pay for will also increase correspondingly, which will increase the labor cost of the enterprise, crowding out the investment in technological progress research and development. From the social perspective, the increasing number of the elderly population will inevitably lead the government to increase the overall expenditure on social security, which will form a certain crowding-out effect on the country's education and R&D investment, thus impeding the overall scientific and technological innovation of the society.

Based on the above theoretical analysis, this paper proposes Hypothesis 1: population aging has a significant negative effect on economic growth in China.

2.2. Analysis on the impact mechanism of population aging on economic growth

Population aging has a complicated impact on the upgrading of industrial structure. This paper explains the impact of population aging on the upgrading of industrial structure from the perspective of supply and demand. From the perspective of supply, the aging of the population mainly affects the upgrading of the industrial structure by influencing the supply of labor and the accumulation of human capital. In the past few decades, labor-intensive low-end industries have dominated China's national economy with the advantage of a "demographic dividend". After entering the 21st century, population aging has accelerated the disappearance of the "demographic dividend", forcing enterprises to gradually transform and increase investment in R&D to promote technological innovation and replace the labor force with technology, thus facilitating the transformation and upgrading of industries. Nevertheless, the shift from relying on a sufficient labor force to using technological factors as a driving force is a gradual process. At present, China's labor-intensive industries still have an important contribution to the national economy, and the impact of population aging on promoting the transformation and upgrading of industries to technology-intensive ones may not be significant in the short term. From the perspective of human capital accumulation, the significant decline in all aspects of the ability of the elderly labor force has seriously affected overall labor productivity. It is hard for the elderly population to adapt to the continuous innovation of knowledge and technology, and it is challenging for them to meet the development requirements of technology-intensive industries, thus limiting the transformation and upgrading of industries. Additionally, the investment in pension security will, to some extent, divert the funds for science and education as well as research and development, which is not conducive to the progress and innovation of technology.

From the demand perspective, population aging can change the consumption demand structure of the market. Different age groups have varying consumption tendencies, and the elderly population has specific consumption needs and preferences for products and services. Therefore, aging can drive the development of the related silver industry, such as the elderly service industry, promoting the upgrading of the industrial structure. The key to whether the promotion effect of the elderly consumption demand on the upgrading of industrial structure is significant lies in the level of economic development, as well as the level of social welfare and the improvement of the social security system. The higher the level of economic development, the better the social welfare, and the more complete the social security system, the higher the willingness and ability of the elderly population to consume, and the greater the release of the elderly consumption demand, resulting in a more significant the effect on the upgrading of the industrial structure. Furthermore, this promotion also depends on the development level of population aging. Only when the degree of aging reaches a certain level can the large-scale consumption demand of the elderly be formed, and the role of promoting the aging industry will be apparent.

Population aging can have a direct impact on economic growth and also indirectly impact it through the upgrading of industrial structure. The upgrading of industrial structure promotes economic growth by improving the operational efficiency of the entire economy. The upgrading of industrial structure generally includes industrial rationalization and industrial optimization. The rational industrial structure emphasizes that each economy should adjust its industrial structure constantly based on its productivity characteristics and factor resource endowment [29], so as to adapt to the actual development status and law, thereby enhancing the stability of economic growth.

Moreover, it further promotes the optimal allocation of production factor resources, which improves the input-output ratio of factors and the production efficiency of various industrial sectors [30,31], thus promoting economic growth. In addition, in the process of industrial structure upgrading, production factors gradually transfer from the low-value-added to the high-value-added, which promotes the optimization of economic structure. An important manifestation of the advanced level of industrial structure development is that the industrial focus shifts towards the secondary and tertiary industries. At the same time, the surplus rural labor force is gradually transferred from rural to urban along with the flow of labor resources, which facilitates the coordinated development of urban and rural areas. In the process of industrial structure upgrading, technological improvement and innovation will be promoted to reduce resource loss and pollution emissions in the production process, which is conducive to promoting green economic development [32,33].

Based on the above theoretical analysis, this paper proposes Hypothesis 2: Industrial structure upgrading plays a mediating role in the impact of population aging on economic growth.

3. Model setting and variable selection

3.1. Model setting

3.1.1. Construction of a static panel data model

Based on the theoretical analysis above, this sub-section constructs a static panel data model to empirically analyze the relationship between population aging and economic growth based on provincial panel data. The benchmark regression model is set as follows.

$$pcgdp_{it} = \alpha_0 + \alpha_1 aging_{it} + \alpha_2 cv_{it} + u_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \tag{1}$$

where i represents a province; t represents a year; the explained variable $pcgdp$ represents the level of economic growth; the explanatory variable $aging$ is population aging; cv is a series of control variables, including government intervention gov and financial development level fin; u_i is the intercept term representing individual heterogeneity, and ε_{it} is the random error term.

When setting up a panel model, the endogenous problem should be considered. On the one hand, there are many factors that affect the economic growth of a region, and some of them cannot be added to the model as explanatory variables because they cannot be quantified, leading to missing variables. On the other hand, population aging can affect economic growth and vice versa. In other words, the relationship between the two is actually interactive. According to the above analysis, the model set in this paper may be endogenous, and optimizing the econometric model is one of the effective methods to solve this problem [34]. Therefore, this paper extends the static panel data model and constructs a dynamic one.

3.1.2. Construction of the dynamic panel data model

In order to solve the endogenous problem which may exist in the static panel data model, this paper constructs a dynamic panel data model to analyze the influence of the aging population on economic growth. Economic growth is dynamic and continuous, which means that the current level of economic growth will be affected by its past level. Therefore, based on Eq (1), the one-period lag

term of economic growth, i.e., $pcgdp_{i,t-1}$, is introduced to build a dynamic panel data model:

$$pcgdp_{it} = \alpha_0 + \alpha_1 aging_{it} + \alpha_2 cv_{it} + \alpha_3\, pcgdp_{i,t-1} + u_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \tag{2}$$

This paper adopts the Gaussian Mixed Model (GMM) to estimate the dynamic panel data model to ensure the consistency and unbiasedness of the estimation coefficients. The GMM method mainly consists of the Differential GMM (DIF-GMM) and the System GMM (SYS-GMM). In the process of model estimation, we need to pay attention to two aspects of test results: one is the sequence correlation test, which requires that the difference term of the random disturbance term does not have second-order or above sequence correlation problems. The other is the over-identification test of instrumental variables, that is, to test the validity of all instrumental variables, usually using the Sargan test statistics and the Hansen test statistics.

3.1.3. Construction of the mediating effect model

To explore the impact mechanism of population aging on economic growth through the upgrading of industrial structure, referring to the research of Wen Zhonglin et al. [35], this paper employs the mediating effect model to test whether there is a mediating effect of industrial structure upgrading in the relationship between population aging and economic growth. The mediating effect model is as follows:

$$pcgdp_{it} = \alpha_0 + \alpha_1 aging_{it} + \alpha_2 cv_{it} + u_{\mathrm{i}} + \varepsilon_{1it} \tag{3}$$

$$upgra_{it} = \beta_0 + \beta_1 aging_{it} + \beta_2 cv_{it} + u_{\mathrm{i}} + \varepsilon_{2it} \tag{4}$$

$$pcgdp_{it} = \gamma_0 + \gamma_1 aging_{it} + \gamma_2 cv_{it} + \gamma_3 upgra_{it} + u_{\mathrm{i}} + \varepsilon_{3it} \tag{5}$$

In Eqs (3)–(5), $upgra$ represents the industrial structure upgrading (including the overall industrial structure upgrading indicator ind, the industrial structure rationalization indicator TL, and the industrial structure optimization indicator TS); α_1 represents the total impact effect of aging on economic growth; γ_1 represents the direct impact effect; $\beta_1 \times \gamma_3$ represents the mediating effect, and the remaining variables are the same as those in Eq (1).

For the test of the mediating effect model, this paper follows the test steps proposed by Wen Zhonglin et al. [35] and combines the Sobel test to test the above formulas one by one to verify the mediating effect of the industrial structure upgrading.

3.2. Variable selection and measurement

The purpose of this paper is to investigate the impact of population aging on economic growth and the mediating role of industrial structure upgrading. Therefore, the explained variable of this paper is economic growth. Based on the research of Qu Xiaoe and Liu Liu, per capita GDP is adopted to measure regional economic growth level [36].

The core explanatory variable of this research is the degree of population aging ($aging$). This paper uses the proportion of the elderly to represent the degree of population aging, specifically referring to the proportion of the elderly aged 65 and above in the total population.

This paper aims to study the mediating transmission mechanism between population aging and

economic growth played by the optimization and upgrading of industrial structure. Therefore, the industrial structure upgrading, the industrial structure optimization, and the industrial structure rationalization are taken as the mediating variables from different dimensions.

First, referring to the method of Xu Min and Jiang Yong [37], an industrial structure upgrading index is constructed to measure the overall upgrading of industrial structure. The calculation formula is as follows:

$$(ind) = \sum_{i=1}^{3} x_i \times i, 1 \leq ind \leq 3 \tag{6}$$

where x_i represents the proportion of the output value of industry i in the total output value. This indicator is adopted to reflect the overall upgrading of the three industries. The larger the value, the higher the overall upgrading and optimization degree of the industrial structure.

Second, based on the research of Gan Chunhui et al. [38], the Thiel index (TL) is used to measure the rationalization degree of industrial structure. The Theil index (TL) is calculated as follows:

$$TL = \sum_{i=1}^{n} (\frac{Y_i}{Y}) \ln (\frac{Y_i/Y}{L_i/L}) \tag{7}$$

where n represents the industry (the study is about three industries, therefore n); Y represents the gross product; L represents the number of the labor force; $\frac{Y}{L}$ refers to the labor productivity; $\frac{Y_i/Y}{L_i/L}$ represents the relative labor productivity of various industries. The closer the value is to 1, the smaller the labor productivity gap between various industries; that is, the higher the coordination degree of the output value structure and the employment structure of various industries, and the more reasonable the industrial structure.

Third, based on the research of Gan Chunhui et al. [38], the ratio of the added value of the tertiary industry to the added value of the secondary industry (TS) is used to measure the industrial structure optimization.

$$TS = \frac{Y_3}{Y_2} \tag{8}$$

where Y_3 is the added value of the tertiary industry and Y_2 the added value of the secondary industry.

Since economic development is a complex process, in addition to population aging, there are many other factors affecting economic growth. Therefore, in order to obtain more accurate and effective results in the study on the impact of population aging on economic growth, this research selects some influential factors as control variables. (1) Government intervention (gov), which can affect not only the allocation of production factors but also the efficiency of factor usage, impacting economic growth from these two aspects. In this paper, the proportion of government fiscal expenditure in GDP is used to represent the intensity of government intervention. (2) Financial development level (fin), which has an effect on economic growth from the aspects of savings rate, investment and capital productivity. Scholars found that the level of financial development can effectively promote economic development [39]. In this paper, the ratio of the loan balance of financial institutions to the total population is used to represent the level of financial development. All variable definitions and descriptions are shown in Table 1.

Table 1. Variable definition and description.

Variable type	Variable name	Sign	Measurement
Explained variable	Economic growth	$pcgdp$	per capita GDP
Explanatory variable	Population aging	$aging$	The proportion of the elderly aged 65 and above in the total population
Mediating variable	Overall industrial structure upgrading	ind	Industrial structure upgrading index
	Industrial structure rationalization	TL	The Theil index
	Industrial structure optimization	TS	The ratio of the added value of the tertiary industry to the added value of the secondary industry
Control variable	Government intervention	gov	The proportion of government fiscal expenditure in GDP
	Financial development level	fin	The ratio of the loan balance of financial institutions to the total population

3.3. Data source

This paper selects the data of 30 provinces in China (excluding Tibet due to missing indicators) from 2000 to 2019 for analysis. The data sources are the provincial statistical yearbooks, the Statistical Yearbook of China's High-tech Industries, the Statistical Yearbook of China's Science and Technology, the Statistical Yearbook of China's Energy, the Statistical Yearbook of China's Environment, the Statistical Yearbook of China's Population and Employment, the Bulletin of National Economic and Social Development and the Wind database. Many indicators cannot obtain direct data, so they are calculated based on the relevant data obtained from the above sources. See Table 2 for variable descriptive statistics.

Table 2. Descriptive statistics of variables.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
$pcgdp$	600	0.1642	0.1108	0.0384	0.7634
$aging$	600	0.098	0.03	0.043	0.242
ind	600	2.3035	0.1352	2.0276	2.832
TS	600	1.0137	0.5408	0.4944	5.1692
TL	600	0.2564	0.1567	0.0174	0.9315
gov	600	0.204	0.095	0.069	0.628
fin	600	4.707	5.292	0.284	35.103

4. Econometric tests of the impact of population aging on economic growth

4.1. Empirical results

The main estimation methods used to estimate the static panel data model include the OLS regression, the random effect (RE), and the fixed effect (FE) methods[1]. In this research, the F test and the Hausman test are used to select the estimation method, and the fixed effect estimation method is finally selected by combining the test results of the two tests. At the same time, this paper also presents the estimation results of the OLS regression and the random effect models for comparison and reference, but the fixed effect estimation results are analyzed in detail. For the dynamic panel data model, the SYS-GMM and the DIF-GMM are selected for estimation. Columns (1)–(3) in Table 3 are the estimation results of the OLS regression, the random effect and the fixed effect of the static panel data model. Columns (4) and (5) are the estimation results of the DIF-GMM and the SYS-GMM of the dynamic panel data model, respectively.

Table 3. Empirical results of the impact of population aging on economic growth.

	(1)	(2)	(3)	(4)	(5)
	OLS	RE	FE	DIF-GMM	SYS-GMM
$lnaging$	−0.0607	−0.0329	−0.0422**	−0.0269***	−0.0288***
	(0.0511)	(0.0210)	(0.0202)	(0.0140)	(0.0158)
$lngov$	−0.482***	−0.288***	−0.0630	−0.180**	−0.0629**
	(0.0638)	(0.0384)	(0.0528)	(0.0887)	(0.0273)
$lnfin$	0.841***	0.526***	0.424***	0.175***	0.128***
	(0.0958)	(0.0329)	(0.0335)	(0.0519)	(0.0449)
$L.lnpcgdp$				0.656***	0.791***
				(0.0646)	(0.0538)
_cons	−0.155	−2.089***	−2.074***		−0.717***
	(0.829)	(0.344)	(0.350)		(0.241)
F test			0.000/24.57		
Hausman test			0.000/67.52		
AR(1)				0.006	0.006
AR(2)				0.115	0.101
Hansen test				0.064	1.000
N	600	600	600	540	570

Note: *, * * and * * * indicate the significance level of 10%, 5% and 1%, respectively; standard errors of regression coefficients are in parentheses.

Population aging has been found to have a significant inhibitory effect on economic growth, as evidenced by the estimated results in Column (3), which show a total effect of −0.0422 at a 5% significance level. Specifically, a 1% increase in the proportion of the elderly is expected to result in

[1] Before parameter estimation, it is necessary to test whether the model meets the classical assumptions. We did not elaborate on the classical assumptions' tests in the paper but tested them in the empirical process and found that all of them had passed. For example, for multicollinearity, we use the stepwise regression to process.

a 0.042% reduction in economic growth. From the estimation results shown in Columns (4) and (5), it can be seen that under the DIF-GMM estimation method, the total effect of population aging on economic growth is −0.0269, and under the systematic GMM estimation method, the total effect is −0.0288, and both pass the test at the 1% significance level. The results indicate that population aging has a significant negative effect on economic growth under the dynamic panel data model. The coefficient of economic growth level with a one-period lag is positive and passes the significance test, and the value is 0.656 under the DIF-GMM estimation method and 0.791 under the SYS-GMM estimation method, indicating strong continuity of economic growth. The estimated coefficients of the explanatory variables in the above models are consistent in terms of signs and significance, which serves to verify the robustness of the established model.

Furthermore, the regression results shown in Columns (4) and (5) provide insight into the effects of various control variables. Specifically, the estimated coefficient of the variable of government intervention is negative, indicating that excessive government intervention can negatively affect economic growth by inhibiting the market's adjustment mechanism, impacting the allocation and efficiency of factor resources, and leading to inefficiency. In contrast, the estimated coefficient of the variable measuring the level of financial development is positive and significant, indicating that higher levels of financial development can promote economic growth by providing the capital necessary to support it [40].

The negative impact of population aging on economic growth can be attributed to several factors. First, population aging reduces the overall labor supply by directly affecting the quantity of labor supply and labor participation rate. Second, the burden of supporting the elderly can crowd out investment in education, which is essential for the accumulation of social human capital. Third, the decline of physical fitness, knowledge and skills of the elderly population can affect individual innovation ability. Meanwhile, the heavy burden of the elderly also hinders the pace of technological innovation of enterprises and society. Fourth, population aging can directly affect the social savings rate, resulting in the reduction of social savings and capital supply, thus affecting economic growth.

4.2. Further analysis on the impact mechanism

In addition, this paper further analyzes the mediating transmission mechanism of industrial structure upgrading in the process of population aging affecting economic growth using the SYS-GMM empirical test. The empirical results are shown in Tables 4 and 5, where Columns (1), (2) and (3) present the results with the overall upgrading of industrial structure (ind) as the mediating variable; Columns (4) and (5) show results with the industrial structure optimization (TS) as the mediating variable, and Columns (6) and (7) display results with the industrial structure rationalization (TL) as the mediating variable.

From the empirical results in Table 4, the overall industrial structure upgrading plays a mediating role in the influence of population aging on economic growth. According to the regression results shown in Columns (1), (2) and (3), the total effect of population aging on economic growth is −0.0288. The estimated coefficient of population aging on the overall industrial structure upgrading is −0.00528, which is significantly negative. The result indicates that population aging has a significant negative impact on the overall industrial structure upgrading. The direct effect of population aging on economic growth is −0.027, which passed the test at the significance level of 10%. The estimated coefficient of the overall industrial structure upgrading is 0.319, which also passed the 10% significance test. This suggests that the overall industrial

structure upgrading has a positive effect on economic growth, indicating its mediating effect.

Table 4. Test results of the mediating effect of the overall industrial structure upgrading.

Variable	(1) $lnpcgdp$	(2) $lnupgra$	(3) $lnpcgdp$
$lnaging$	−0.0288*	−0.00528**	−0.0270*
	(0.0158)	(0.00255)	(0.0161)
$lngov$	−0.0629**	−0.00498**	−0.0614**
	(0.0273)	(0.00246)	(0.0246)
$lnfin$	0.128***	0.0173***	0.115***
	(0.0449)	(0.00461)	(0.0427)
$lnupgra$			0.319*
			(0.419)
$L.lnpcgdp$	0.791***		0.770***
	(0.0538)		(0.0586)
$L.lnupgra$		0.831***	
		(0.0520)	
_cons	−0.717***	0.198***	−1.104*
	(0.241)	(0.0675)	(0.598)
AR(1)	0.006	0.000	0.007
AR(2)	0.101	0.857	0.1
Hansen test	1.000	1.000	1.000
N	570	570	570

Note: *, * * and * * * indicate the significance level of 10%, 5% and 1%, respectively; standard errors of regression coefficients are in parentheses.

The empirical results in Table 5 show that the industrial structure optimization plays a mediating role in the impact of population aging on economic growth. Column (4) presents that the estimated coefficient of population aging is −0.0638, which is significant at the 1% level. The result indicates that population aging is not conducive to the development of China's industrial structure optimization. The regression results in Column (5) show that the estimated coefficient of population aging is significantly negative, with a value of −0.0115, and the coefficient of the industrial structure optimization is 0.0023, indicating that the industrial structure optimization can effectively promote economic growth, thus playing a mediating role. Population aging not only directly hinders economic growth but also indirectly affects economic growth through industrial structure optimization.

Additionally, the results in Table 5 also indicate that the industrial structure rationalization plays a mediating role in the impact of population aging on economic growth. It can be seen from Column (6) that the coefficient of population aging is 0.0701. Since the Tyle index (TL) is a negative indicator; that is, the smaller the value is, the higher the degree is. Therefore, the effect of population aging on the industrial structure rationalization is negative, hindering the process of industrial structure rationalization. According to the regression results in Column (7), the estimated coefficient of population aging is negative, and the specific value is −0.0271, which is significant at the 10% level.

Since industrial structure rationalization is a negative indicator, the negative coefficient indicates that industrial structure rationalization has a positive effect on economic growth. The higher the industrial structure rationalization is, the higher the level of economic development is, indicating that the industrial structure rationalization has a partial mediating effect.

Table 5. Test results of the mediating effect of industrial structure optimization and rationalization.

Variable	(4) $lnts$	(5) $lnpcgdp$	(6) $lntl$	(7) $lnpcgdp$
$lnaging$	−0.0638***	−0.0115*	0.0701*	−0.0271*
	(0.0206)	(0.0158)	(0.351)	(0.0157)
$lngov$	0.0177	−0.0431**	0.0744**	−0.0552**
	(0.0208)	(0.0202)	(0.0354)	(0.0250)
$lnfin$	0.0761**	0.0961***	−0.0768*	0.115***
	(0.0327)	(0.0372)	(0.0462)	(0.0415)
$lnts$		0.0023*		
		(0.0377)		
$lntl$				−0.00525*
				(0.0149)
$L.lnpcgdp$		0.8102***		0.795***
		(0.0610)		(0.0549)
$L.lnts$	0.918***			
	(0.0377)			
$L.lntl$			0.928***	
			(0.0316)	
_cons	0.139	−0.789	0.202	−0.781***
	(0.327)	(0.501)	(0.437)	(0.276)
AR(1)	0.000	0.007	0.029	0.006
AR(2)	0.307	0.105	0.310	0.105
Hansen test	1.000	1.000	1.000	1.000
N	570	570	570	570

Note: *, * * and * * * indicate the significance level of 10%, 5% and 1%, respectively; standard errors of regression coefficients are in parentheses.

Based on the empirical results of the mediating effect model, it can be concluded that population aging has a significantly negative effect on the industrial structure upgrading, which has played a mediating effect between population aging and economic growth. The overall industrial structure upgrading, the industrial structure rationalization and the industrial structure optimization have significant mediating effects, showing the transmission mechanism from population aging through industrial structure upgrading to economic growth. Hypothesis 2 is therefore verified.

5. Conclusions and policy implications

5.1. Conclusions

Based on the data of 30 provinces in the Chinese Mainland from 2000 to 2019, this paper empirically tests the impact of population aging on economic growth and its impact mechanism by using the static panel data model, the dynamic panel data model and the mediating effect model on the basis of theoretical analysis. The conclusions are as follows.

First, population aging has a significant negative impact on economic growth in China. Through a combination of static and dynamic analysis, this study found that the total effect of population aging on economic growth is negative, indicating that population aging significantly hinders economic growth in China.

Second, industrial structure upgrading plays a mediating role in the impact of population aging on economic growth. According to the regression results of the mediating effect model, population aging has negative effects on the overall industrial structure upgrading, the industrial structure optimization and the industrial structure rationalization, indicating that the aggravation of population aging has a significant negative impact on the optimization and upgrading of industrial structure. Therefore, in the process of population aging restraining economic growth, industrial structure upgrading plays a partial mediating effect. That is, population aging not only directly hinders economic growth but also indirectly affects economic growth by influencing industrial structure upgrading.

5.2. Policy implications

Given the impact of demographic change on economic growth, policymakers should timely introduce various countermeasures for “active aging”, including the following aspects.

Firstly, governments should accelerate economic development and transform the economic developing pattern. Judging from the historical experience of other countries, economic strength is the key to easing the problem of population aging. Thus, at the macroeconomic level, efforts should be made to transition from a traditional factor-driven mode to an innovation-driven mode. This can be achieved by enhancing the driving force of innovation, improving the utilization rate of resources, and enhancing social productivity. In this way, the level of social welfare and material reserves can meet the normal needs of society and cope with the increasingly serious imbalance in the population structure.

Secondly, governments should improve and adjust the fertility policy. The construction of supporting security systems should be accelerated to reduce the pressure on population fertility. It is necessary to make a comprehensive breakthrough in concept from the perspective of policy improvement. The government should comprehensively consider social security, housing, and the construction of medical care system for women and infants.

Thirdly, governments at all levels should support the high-quality development of the emerging aging industry. The rapid growth of aging population not only brings negative effects but also promotes the development of emerging industries. For example, research and development investment in the intelligent elderly care industry, such as intelligent appliances, special equipment, and facilities for rehabilitation care, can meet the “silver market” by combining with tourism,

medical, health, sports and other different industries. Companies must design exclusive products to meet the needs of elderly customers, including product customization, health management, property protection, legal counsel, and other special value-added services.

Fourthly, governments should improve the old-age security and service system. With a focus on basic old-age insurance, governments should accelerate the improvement of the old-age insurance system for urban workers and non-working urban and rural residents. In addition, governments should improve the medical insurance system, explore the ways to establish a long-term care insurance system, improve the social welfare and social assistance systems for the elderly, and develop public welfare charities.

5.3. Research prospects

Due to the length limitation and specific objectives of this study, there are several aspects that could be further explored in future research.

First, the heterogeneous impact of population aging on economic growth in China can be explored. This paper studies the impact of population aging on economic growth as well as the impact mechanism from a macro perspective. However, different provinces with various population structures may affect the results and mechanisms, showing heterogeneous characteristics, which deserve further research.

Second, the impact of population aging on the quality of economic growth is worth studying. Unexpected outputs can arise in the process of economic growth, and population aging can affect the quality of economic growth in China, particularly in the context of carbon peaking and carbon neutrality. Future studies could explore this relationship in greater detail.

Third, research on the substitution of digital economy and population aging is worth exploring. With the rise of information technology, it is worth exploring whether there is a substitution effect between data as a factor of production and the labor force provided by the population, and if so, what the intensity of the substitution effect is. These questions are worth further study.

Acknowledgments

This research was funded by the National Social Science Fund 22BTJ053 and the Excellent Youth Project of Hunan Province Education Department 20B159.

Conflict of interest

The authors declare no conflict of interest.

References

1. E. Kim, G. J. D. Hewings, C. Lee, Impact of educational investments on economic losses from population ageing using an interregional CGE-population model, *Econ. Model.*, **54** (2016), 126–138. https://doi.org/10.1016/j.econmod.2015.12.015
2. F. Lancia, G. Prarolo, A politico-economic model of aging, technology adoption and growth, *J. Popul. Econ.*, **25** (2012), 989–1018. https://doi.org/10.1007/s00148-011-0364-x

3. Y. Su, Z. Li, C. Yang, Spatial interaction spillover effects between digital financial technology and urban ecological efficiency in China: an empirical study based on spatial simultaneous equations, *Int. J. Environ. Res. Public Health*, **18** (2021), 8535. https://doi.org/10.3390/ijerph18168535
4. Y. Liu, P. Failler, Z. Liu, Impact of environmental regulations on energy efficiency: a case study of China's air pollution prevention and control action plan, *Sustainability*, **14** (2022), 3168. https://doi.org/10.3390/su14063168
5. Z. Li, G. Liao, K. Albitar, Does corporate environmental responsibility engagement affect firm value? The mediating role of corporate innovation, *Bus. Strateg. Environ.*, **29** (2020), 1045–1055. https://doi.org/10.1002/bse.2416
6. C. Y. Horioka, Aging and saving in Asia, *Pac. Econ. Rev.*, **15** (2010), 46–55. https://doi.org/10.1111/j.1468-0106.2009.00489.x
7. Z. H. Li, J. H. Zhu, J. J. He, The effects of digital financial inclusion on innovation and entrepreneurship: a network perspective, *Electron. Res. Arch.*, **30** (2022), 4697–4715. https://doi.org/10.3934/era.2022238
8. M. B. Mimi, Md. Ahasan Ul Haque, Md. Golam Kibria, Does human capital investment influence unemployment rate in Bangladesh: a fresh analysis, *National Accounting Review*, **4** (2022), 273–286. https://doi.org/10.3934/NAR.2022016
9. F. Sardo, Z. Serrasqueiro, Intellectual capital and high-tech firms' financing choices in the European context: a panel data analysis, *Quant. Financ. Econ.*, **5** (2021), 1–18. https://doi.org/10.3934/QFE.2021001
10. M. Gonzalez-Eiras, D. Niepelt, Ageing, government budgets, retirement, and growth, *Eur. Econ. Rev.*, **56** (2012), 97–115. https://doi.org/10.1016/j.euroecorev.2011.05.007
11. J.-M. Le Page, Structural rate of unemployment, hysteresis, human capital, and macroeconomic data, *National Accounting Review*, **4** (2022), 135–146. https://doi.org/10.3934/NAR.2022008
12. Y. Y. Huang, Q. Guo, M. X. Xiao, The unbalanced development and trends of China's regional tourism, *National Accounting Review*, **3** (2021), 69–85. https://doi.org/10.3934/NAR.2021003
13. Z. Li, H. Chen, B. Mo, Can digital finance promote urban innovation? Evidence from China, *Borsa Istanbul Rev.*, in press. https://doi.org/10.1016/j.bir.2022.10.006
14. Y. Liu, P. Failler, Y. Ding, Enterprise financialization and technological innovation: mechanism and heterogeneity, *PLoS ONE*, **17** (2022), e0275461. https://doi.org/10.1371/journal.pone.0275461
15. L. Q. Zhao, Z. Y. Han, The research of economic development under the background of population aging in China, (Chinese), *On Economic Problems*, 2015, 40–44.
16. F. Gong, Z. Wang, J. Yu, Aging population, generational balance, and public welfare expenditure, *Economic Research Journal*, **54** (2019), 103–119.
17. M. Fougere, S. Harvey, J. Mercenier, M. Mérette, Population ageing, time allocation and human capital: a general equilibrium analysis for Canada, *Econ. Model.*, **26** (2009), 30–39. https://doi.org/10.1016/j.econmod.2008.05.007
18. Z. Li, C. Yang, Z. Huang, How does the fintech sector react to signals from central bank digital currencies?, *Financ. Res. Lett.*, **50** (2022), 103308. https://doi.org/10.1016/j.frl.2022.103308
19. S. Y. Ren, H. T. Wu, Path to green development: the role environmental regulation and labor skill premium on green total factor energy efficiency, *Green Finance*, **4** (2022), 387–410. https://doi.org/10.3934/GF.2022019

20. Y. Liu, Z. Li, M. Xu, The influential factors of financial cycle spillover: evidence from China, *Emerg. Mark. Financ. Tr.*, **56** (2020), 1336–1350. https://doi.org/10.1080/1540496x.2019.1658076
21. I. Semenenko, Y. Bilous, R. Halhash, The compliance of the regional development strategies and funding with the sustainable development concept: the case of Ukraine, *Green Finance*, **4** (2022), 159–178. https://doi.org/10.3934/GF.2022008
22. D. Qiu, D. J. Li, Comments on the "SSF Report" from the perspective of economic statistics, *Green Finance*, **3** (2021), 403–463. https://doi.org/10.3934/GF.2021020
23. G. K. Liao, P. Hou, X. Shen, K. Albitar, The impact of economic policy uncertainty on stock returns: the role of corporate environmental responsibility engagement, *Int. J. Financ. Econ.*, **26** (2021), 4386–4392. https://doi.org/10.1002/ijfe.2020
24. J. P. Ansah, R. L. Eberlein, S. R. Love, M. A. Bautista, J. P. Thompson, R. Malhotra, et al., Implications of long-term care capacity response policies for an aging population: a simulation analysis, *Health Policy*, **116** (2014), 105–113. https://doi.org/10.1016/j.healthpol.2014.01.006
25. Y. Liu, C. Ma, Z. Huang, Can the digital economy improve green total factor productivity? An empirical study based on Chinese urban data, *Math. Biosci. Eng.*, **20** (2023), 6866–6893. https://doi.org/10.3934/mbe.2023296
26. M. Gonzalez-Eiras, D. Niepelt, Aging, government budgets, retirement, and growth, *Eur. Econ. Rev.*, **56** (2011), 97–115. https://doi.org/10.1016/j.euroecorev.2011.05.007
27. K. Davis, The theory of change and response in modern demographic history, *Population Index*, **9** (1963), 345–352. https://doi.org/10.2307/2732014
28. D. J. van de Kaa, The idea of a second demographic transition in industrialized countries, *Sixth Welfare Policy Seminar of the National Institute of Population and Social Security*, 29 January 2022, 1–34.
29. B. Siliverstovs, K. A. Kholodilin, U. Thiessen, Does aging influence structural change? Evidence from panel data, *Econ. Syst.*, **35** (2011), 244–260. https://doi.org/10.1016/j.ecosys.2010.05.004
30. M. Ahmed, M. Azam, S. Bekiros, S. M. Hina, Are output fluctuations transitory or permanent? New evidence from a novel Global Multi-scale Modeling approach, *Quant. Financ. Econ.*, **5** (2021), 373–396. https://doi.org/10.3934/QFE.2021017
31. P. Ilmakunnas, S. Ilmakunnas, Work force ageing and expanding service sector: a double burden on productivity?, *Serv. Ind. J.*, **30** (2010), 2093–2110. https://doi.org/10.1080/02642060903199838
32. Z. Li, F. Zou, B. Mo, Does mandatory CSR disclosure affect enterprise total factor productivity?, *Economic Research-Ekonomska Istraživanja*, **35** (2022), 4902–4921. https://doi.org/10.1080/1331677X.2021.2019596
33. Z. Li, Z. Huang, Y. Su, New media environment, environmental regulation and corporate green technology innovation: evidence from China, *Energ. Econ.*, **119** (2023), 106545. https://doi.org/10.1016/j.eneco.2023.106545
34. D. Qiu, D. Li, Paradox in deviation measure and trap in method improvement—take international comparison as an example, *Quant. Financ. Econ.*, **5** (2021), 591–603. https://doi.org/10.3934/QFE.2021026
35. Z. Wen, L. Chang, H. Tai, H. Liu, Testing and application of the mediating effects, *Acta Psychologica Sinica*, **36** (2004), 614–620.

36. X. Qu, L. Liu, Impact of environmental decentralization on high-quality economic development, (Chinese), *Statistical Research*, **38** (2021), 16–29. https://doi.org/10.19343/j.cnki.11-1302/c.2021.03.002
37. M. Xu, Y. Jiang, Can the China's industrial structure upgrading narrow the gap between urban and rural consumption?, *The Journal of Quantitative & Technical Economics*, **32** (2015), 3–21.
38. C. Gan, R. Zheng, D. Yu, An empirical study on the effects of industrial structure on economic growth and fluctuations in China, *Economic Research Journal*, **46** (2011), 4–16.
39. Z. Li, Z. Huang, H. Dong, The influential factors on outward foreign direct investment: evidence from the "The Belt and Road", *Emerg. Mark. Financ. Tr.*, **55** (2019), 3211–3226. https://doi.org/10.1080/1540496x.2019.1569512
40. Z. Li, B. Mo, H. Nie, Time and frequency dynamic connectedness between cryptocurrencies and financial assets in China, *Int. Rev. Econ. Financ.*, 2023, in press. https://doi.org/10.1016/j.iref.2023.01.015

AIMS Press

© 2023 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)