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The Role of Population Aging in High-Quality Economic Development: Mediating Role of Technological Innovation

Wenqun Gao[1], Yang Chen[1], Shaorui Xu[2], Oleksii Lyulyov[3,4], and Tetyana Pimonenko[3,4]

Abstract

This paper aims to research the relationship between population aging, technological innovation, and high-quality economic development. The study applies the spatial econometric model and the intermediary effect model. The object of investigation is 31 provinces in China from 2013 to 2020. The results show that population aging has a significant effect on technological innovation and high-quality economic development. In addition, population aging promotes technological innovation and is further conducive to high-quality economic development. In addition, the impact of population aging on high-quality economic development is regionally heterogeneous. Thus, population aging in the eastern and central regions stimulates technological innovation to have a positive impact on high-quality economic development. Population aging in the western region inhibits technological innovation and has a negative impact on high-quality economic development. Based on this, the study proposes countermeasures to promote high-quality economic development.

Keywords

population aging, technological innovation, high-quality economic development, spatial measurement, intermediary effect

Introduction

Experts from the United Nations highlight that the global population is aging (United Nations, 2022), and the number and proportion of the aging population is increasing in every country in the world. Scholars (Mason & Lee, 2022) have proven that the problem of population aging has already become one of the most important social trends in the 21st century, affecting labor (Olivieri et al., 2022; Tan et al., 2022), finance (Dzogbenuku et al., 2022; Guan et al., 2022), housing (Alhodiry et al., 2021; Chum et al., 2022; Gong & Yao, 2022), the environment (M. Ali et al., 2022; H. Chen et al., 2022; Ginevičius, Nazarko et al., 2021; Us et al., 2022; Yu et al., 2022), and social security (Crist et al., 2022; Gelber et al., 2022; Yula et al., 2020). According to the Main Data of the Seventh National Population Census (2021), in China, the population aged 60 or above accounts for more than 18%, and the number of people aged 65 or over is 200.56 million, accounting for 14.2% of the total population. China's aging population is accompanied by a low birth rate, low fertility rate and aging before becoming rich (G. Liu & Zhang, 2022).

The report of the The Nineteenth National Congress of the Communist Party of China (2017) notes that China's economy has shifted from the stage of high-speed growth to the stage of high-quality economic development within extending technological innovation (HQED). It should be noted that human resources are the core driver of a country's development, and they are the basis of the innovation capacity of the country. At the same time, aging limits the country's growth in the long term and consequently restricts the spread of

[1]Fujian Normal University, Fuzhou, P. R. China
[2]Xiangtan University, P. R. China
[3]WSB University, Poland
[4]Sumy State University, Ukraine

Corresponding Author:
Tetyana Pimonenko, Department of Marketing, Sumy State University, 40007, Sumy, str. Kharkivska 116, Ukraine.
Email: tetyana_pimonenko@econ.sumdu.edu.ua

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knowledge and innovations and the country's economic development (Davis et al., 2022; Jin & Brigitte, 2019). Furthermore, past studies (Dosi et al., 2022; Moyo et al., 2021; Su et al., 2022; Z. Xie et al., 2022) confirm that technological innovation is directly affected by the age structure of the population. In 2022, the Chinese government declared the necessity to actively react to the increasing pressure of aging and improve the quality of scientific and technological innovation without restricting HQED. The acceleration of population aging provokes an increase in investment in social security, such as medical care and pensions. Consequently, it will reduce the state financing of expenditures on research and development and education and further directly affect the material basis of economic innovation and development. On the other hand, with the decline in the physical fitness of the elderly group, the demand for new knowledge and skills will decrease, and the motivation for scientific and technological innovation will be weakened. In contrast, the elderly population will pay more attention to the education of their children. Consequently, the quality of human capital will improve, which could promote HQRD and extend innovation. According to life cycle theory (Vendrell-Herrero et al., 2022), population savings and consumption behavior depend on different life stages. In this case, the paper aims to analyze the impact of population aging on scientific and technological innovation and HQED to justify the relevant instruments to overcome the issues that could be provoked by aging.

The paper contributes to the theoretical framework of population aging and its impact on regional growth by developing approaches for (1) assessing HQED based on the entropy method and region segmentation on HQED based on the local Moran index; (2) exploring the impact of population aging on HQED and innovations based on spatial autoregressive, error and Durbin models; and (3) analyzing the mediating role of technological innovation in linking the aging population and HQED. The paper has the following structure: Literature Review—analysis of the theoretical background of population aging within consequences on innovation and HQED to justify the research hypothesis; Materials and Methods—explanation of selected variables, models and instruments to check the research hypothesis; Results—describing findings of the investigation; Discussion—comparison analysis of the obtained findings with the previous investigations; Conclusions—explanation of core results, limitations and further directions for investigations.

Literature Review

HQED and Population Aging

The results of the analysis of the theoretical background on the relationship between population aging and HQED allow the identification of controversial points of view among the scientific community. First, population aging is conducive to HQED. The 20th century was a century of population growth, while the 21st century will go down in history as a century of population aging (Lunenfeld, 2008). Aging expands per capita productive capacity and contributes to economic growth more than reliance on population growth (D. E. Bloom & Williamson, 1998; Hoxhaj et al., 2022). In the short term, aging will improve the living standards of residents (Cutler et al., 1990; Skvarciany & Vidžiūnaitė, 2022), cause future consumer demand growth (DellaVigna & Pollet, 2007), improve social welfare (Davis et al., 2022), increase the quantity and quality of human capital (Hanić & Jevtić, 2020; C. Liu & Lin, 2020), and enhance fiscal sustainability (Cao et al., 2022). Second, the aging of the population is not conducive to achieving HQED. Population aging has a significant negative effect on HQED (D. He & Liu, 2020), and the eastern region is less affected than the central and western regions. Whether population aging is conducive to long-term economic growth depends on the relative change between fertility and mortality, with fertility and per capita output positively correlated and mortality and per capita output negatively correlated (Prettner, 2013). Third, there is the spatial effect of population aging and HQED. While promoting the HQED of the region, the aging population will also adversely affect the HQED of the surrounding areas (Fu & Cao, 2021). J. He et al. (2021) underline that the proportion of old age in this region not only has an inverted U-shaped impact on the economic growth of the region but also has an indirect impact on the economic growth of neighboring regions.

Hypothesis 1: Aging of the population effects on HQED.

The Relationship Between Population Aging and Technological Innovation

Baldanzi et al. (2019) and Deng and Zhang (2018) justify that aging positively impacts technological innovation. Thus, Baldanzi et al. (2019) shows that aging leads to an increase in life expectancy, aggregate savings, and demand for innovation, leading to higher employment in the R&D sector, faster technological progress, and higher rates of long-term economic growth. Baldanzi et al. (2019) underlines that technology development and implementation are being strongly driven by demographic changes around the world (Baldanzi et al., 2019), especially in rapidly aging countries such as Germany, Japan, and South Korea. The adoption of automation technology is faster in countries with aging populations (Acemoglu & Restrepo, 2017). Aging promotes technological innovation through the structure of "capital-labor" elements and the improvement of the quality of human capital elements (Deng & Zhang, 2018). On the other hand, Yao et al. (2017) prove that aging negatively affects technological innovation due to the lack of human capital stock (Yao et al., 2017). The growth of the proportion of the child population significantly inhibits technological innovation (Jin & Brigitte, 2019). In addition, there is a significant inverted U-shaped relationship and heterogeneous threshold effect between population aging and Chinese scientific and technological innovation (Lou et al., 2020). The aging of the population decreases labor productivity, and the government, consequently, should increase financial support for education, science, and technology (Dzwigol, 2022; Shikata et al., 2021), improve the comprehensive quality of the labor force, increase the number of high-tech talents, and promote the improvement of human capital to promote technological innovation and progress.

> **Hypothesis 2:** Aging population effects on technological innovation.

HQED, Population Aging and Technological Innovation

Population aging has a positive impact on HQED through technological progress and negative effects through pure technological efficiency and scale efficiency (J. Li & Gao, 2020). Promoting technological innovation can offset the negative impact of aging to a certain extent, thereby promoting sustained economic growth (X. Xie & Zhu, 2020). With the improvement of education level, a high-quality labor force can promote economic growth by improving technological innovation and technology application after entering the aging period (Wang & Wang, 2017). In addition, population aging inhibits the role of enterprise innovation in promoting HQED (Cao et al., 2022). At the same time, Diebolt and Hippe (2019) conclude that innovations play a core role in accumulating intellectual capital and consequently lead to economic development. N. Bloom et al. (2019) confirm the causal relationship between intellectual capital and a country's development within extending research and development. Kowal and Paliwoda-Pękosz (2017) empirically justify that innovations have an intermediary role in enhancing economic growth and accumulating human capital within overcoming issues caused by the aging of the population.

> **Hypothesis 3:** Technological innovation plays a mediating role in the link between population aging and HQED.

Materials and Methods

Specification of Variables

Explained Variable. The results of the theoretical analysis confirm that HQED reveals quantitative and qualitative growth in four directions (innovation, coordination, sustainable development, openness and sharing), one of which is explained by the separate range of the indicators (Table 1). Based on previous studies (Arefieva et al., 2021; Dziadzia et al., 2019; Rozmiarek et al., 2022), this investigation applies an integrated index for the comprehensive assessment of all HQED areas of the region.

The study applies the entropy approach to estimate HQED, which consists of the following stages:

Step 1: The standardization of variables x_{ij}, which reveal the innovation, coordination, sustainable development, openness and sharing dimensions of HQED:

Positive indicators:

$$x^*_{ij} = \frac{x_{ij} - m_j}{M_j - m_j} \quad (1)$$

Negative indicators:

$$x^*_{ij} = \frac{M_j - x_{ij}}{M_j - m_j} \quad (2)$$

$$M_j = max\{x_{ij}\} m_j = min\{x_{ij}\} \quad (3)$$

Step 2: Assessment of weight for standardized indicators:

$$w_j = \frac{d_j}{\sum_{i=1}^{n} d_j} \quad (4)$$

where w_j—the weight coefficients j standardized indicators measured in the interval between 0 and 1; d_j—the information entropy redundancy:

$$d_j = 1 - e_j \quad (5)$$

where e_j is the information entropy of each component based on the specific gravity:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{m} p_{ij} \ln(p_{ij}) \quad (6)$$

where p_{ij}—the index proportion:

Table 1. The Index System for HQED.

Level	Indicators	Variables	Metrics measure	Unit	Attribute
Innovation	Input	R&D funding input intensity	R&D expenditure/GDP	%	+
		R&D personnel input	Number of R&D employees	Person	+
		R&D internal activity funding	R&D internal activity funding	Ten thousand yuan	+
		R&D new product development funds	R&D new product development funds	Ten thousand yuan	+
	Output	R&D New Product sales revenue	R&D New Product sales revenue	Ten thousand yuan	+
		Total profits of high-tech industries	Total profits of high-tech industries	Ten thousand yuan	+
		Number of valid R&D invention patents	Number of valid R&D invention patents	Item	+
Coordinate	Growth coordination	Employment stability	Registered urban unemployment rate	%	-
		Financial self-sufficiency coefficient	Fiscal expenditure/fiscal revenue	%	+
		Government debt burden	(General budget expenditure-General budget revenue of local finance)/G DP	%	–
	Industrial structure	Industrial structure advanced index	Output value of the tertiary industry/secondary industry	%	+
	Urban and rural structure	Urbanization process	Urbanization rate	%	+
		Coordination between urban and rural incomes	Urban per capita disposable income/rural per capita disposable income	%	–
Sustainable Development	Energy consumption	Power consumption	Total electricity consumption	One hundred million kilowatt-hours	–
	Environmental pollution	Unit output of wastewater and solid waste	Waste discharge/ten million yuan of GDP	Ton	–
		Wastewater per unit of output	Total wastewater discharge/ GDP	Ton	-
		Waste gas per unit of output	Sulfur dioxide emissions/ GDP	%	-
	Greens environmental protection	urban green coverage	Urban green area/China land area	%	+
		Per capita has the park green space area	Park green space area/ population number	m^2	+
		harmless disposal rate of household garbage	harmless disposal rate of household garbage	%	+
Sharing	Infrastructure	Improvement of educational facilities	Public library collections/ population numbers	Person	+
		Improvement of medical facilities	Number of beds/population in medical institutions	Person	+
		Improvement of transportation facilities	Public transport vehicles per 10,000 people	Ten thousand people	+
		Improvement of network facilities	Number of Internet broadband interfaces/ population	person	+
	People's life	Per capita education expenditure	Education expenditure/ population count	Yuan/person	+
		Per capita disposable income	Densable income/population count	Yuan/person	+
		Index of consumption	Retail sales of social consumer goods/GDP	%	+
		Consumption of urban～rural gap	Per capita consumption expenditure of urban residents/rural residents × 10,000	Yuan/person	-

$$p_{ij} = x_{ij}^* / \sum_{i=1}^{n} x_{ij}^* \quad (7)$$

Step 3: Assessment of composite indicators of HQED:

$$HQED_{it} = \sum_{j=1}^{n} w_j \times x_{ij}^* \quad (8)$$

Explanatory Variables. This paper uses the aging index (Aging), which is measured by the number of elderly people per 100 people younger than 14 years old. Old—measure the degree of population aging, among which the aging ratio is the proportion of the population over 65 years old in the total population.

Control Variables. The following variables were selected as the control variables:

- the degree of economic development (measured by per capita GDP (Pgdp). Gradual economic growth allows regions to transition from traditional extensive economic growth to the efficient, innovative, environmentally friendly and green development model (Duc Truong et al., 2022; Gavkalova et al., 2022; Kuzior, Grebski et al., 2022). With the continuous deepening of the aging process of the population, the elderly population has low energy consumption, which is conducive to the improvement of environmental quality. The elderly have a high awareness of environmental protection, are willing to save resources, and prefer green life products. As the physical quality of the elderly gradually declines, the requirements for the environment and quality of life gradually increase, and the government will increase investment in environmental governance to meet the needs of elderly individuals, which is conducive to the improvement of environmental quality. On the other hand, the increase in the level of population aging will lead to an increase in expenses for elderly individuals, medical care, and other aspects, which will eventually lead to a decrease in the country's investment in environmental governance, which is not conducive to the improvement of environmental quality (Artyukhov et al., 2021; Smiianov et al., 2020);
- industrial structure (is measured by the ratio of secondary industry output to regional gross domestic product (Str)), industrialization leads to rapid economic growth with an increased negative impact on the attainment of sustainable development. With the acceleration of aging, the consumption structure of more elderly people is changing from the original food to medical consumption. The deepening of aging provokes the decline of working people. This, consequently, leads to the transfer of the agricultural population to the nonagricultural population, which is conducive to an advanced industrial structure, thereby accelerating the upgrading of the industrial structure (Czyżewski & Polcyn, 2016; Kwilinski, Zaloznova et al., 2020).
- financial support (is fiscal expenditures measured as a share of regional gross domestic product (Gov). This indicator measures the intensity of state intervention in the economy of each region. With the increase in the elderly population and the decline in the labor force, the income level of the elderly population widens the gap between the rich, the national public policy begins to tilt toward elderly individuals, and social wealth begins to shift toward elderly individuals, increasing the proportion of pension and medical social security expenditure and promoting social wealth, thus promoting HQED (Kwilinski, Dielini et al., 2020).
- the degree of marketization (Mar)—a higher degree of marketization reveals the capabilities of the market to regulate resource distribution and could affect HQED (Fan et al., 2016; Ramadania et al., 2022);
- the urbanization rate (measured by the proportion of the urban population in the total population (Urb)). Urbanization is characterized by the concentration of economic, demographic and political capcity, which makes it possible to concentrate and control significant financial resources, create new technologies and new types of services, and carry out innovative activities (Szczepańska-Woszczyna et al., 2022);
- trade openness (measured by the proportion of the regional import and export trade volume in the production value (Open)). China's open economic development is mainly reflected in the current account balance and import and export trade. The current account is a record of production, income distribution, redistribution, and income use account, including the production account, income distribution and use account. The account is through the balance item, and population aging will produce greater downward pressure on social savings, which may affect the balance of the current account. Export trade refers to the sale of goods produced or processed goods to overseas markets. The aggravation of the elderly population will cause the supply of labor to decrease, leading to the cost of labor, which will affect the

development of international trade. At the same time, the aging population will promote the transformation and upgrading of China's import and export trade structure, and enterprises will continue to increase investment in science and technology to further enhance the level of opening-up (Kwilinski et al., 2022).
- *Intermediation variable*. Based on Yu et al. (2016), technological innovation (measured by the number of per capita patents granted (Inn)) is used as the intermediation variable in linking population aging and HQED.

The research object of this paper is 31 Chinese provinces (cities) and autonomous regions (excluding Hong Kong, Macao and Taiwan), and 31 provinces are selected from 2010 to 2019 panel data. All data are from the China Statistical Yearbook, China Statistical Yearbook of Science and Technology, China Population and Employment Statistical Yearbook, China High-tech Industry Statistical Yearbook, National Bureau of Statistics (2022), and provinces (city) statistics bureau official website. Part of the data is needed to calculate the results.

Model Specification

Spatial Measurement Model. To study the influence of adjacent area behavior on the behavior of other regions of the system, the spatial lag model (SAR) is used, see specifically in formula (9); when the relationship between regions is reflected by random interference items, the spatial error model (SEM) is used, see formula (10), and the spatial Durbin model (SDM) is used in the spatial lag model, see formula (12). The details are as follows:

Spatial autoregressive model (SAR):

$$HQED_{it} = \lambda \sum_{j=1}^{n} W_{it} Aging_{it} + \beta DIF_{it} + \varepsilon_{it} \tag{9}$$

Spatial Error Model (SEM):

$$HQED_{it} = \beta Aging_{it} + \mu_{it} \tag{10}$$

$$\mu_{it} = \rho \sum_{j=1}^{n} W_{ij} \mu_{jt} + \varepsilon_{it}, \varepsilon \sim N(0, \sigma^2 \ I_n) \tag{11}$$

Spatial Durbin Model (SDM):

$$HQED_{it} = \lambda \sum_{j=1}^{n} W_{ij} HQED_{jt} + \beta Aging_{jt} + \sum_{j=1}^{n} W_{ij} \delta + \varepsilon_{it} \tag{12}$$

where i and t indicate provinces and years, λ represents the spatial lag coefficient, ρ represents the spatial error coefficient, and β and δ are the parameters to be estimated. W_{ij} is a normalized n*n-dimensional i-row j column of the spatial weight matrix.

The Mediation Effect Model

To deeply explore the intermediary effect of technological innovation on HQED, this paper adopts the gradual (step-by-step) regression method to construct the intermediary effect model, as shown in Equations 13 to 15:

$$HQED_{it} = \gamma_0 + \alpha_1 Aging_{it} + \varphi_{ij} \sum_{j=1}^{n} X_{ij} + \mu_{it} \tag{13}$$

$$Inn_{it} = \gamma_0 + \beta_1 Aging_{it} + \varphi_{ij} \sum_{j=1}^{n} X_{ij} + \mu_{it} \tag{14}$$

$$HQED_{it} = \gamma_0 + \gamma_1 Aging_{it} + \gamma_2 Inn_{it} + \varphi_{ij} \sum_{j=1}^{n} X_{ij} + \mu_{it} \tag{15}$$

where $HQED_{it}$ represents high-quality economic development; $Aging_{it}$ represents the population aging index, Inn_{it} represents technological innovation; X_{ij} represents the control variable; and μ_{it} represents the random interference term.

Spatial Correlation Test. First, the four spatial weight matrices are constructed, and then formulas 16–19 are used to test the spatial correlation of the HQED of China.

1. The adjacency space matrix, a simple binary space weight matrix, is set as follows:

$$W_{i,j} = \begin{cases} 1, \ i = j \\ 0, i \neq j \end{cases} \tag{16}$$

2. The geospatial matrix is set as follows:

$$W_{i,j} = \begin{cases} \frac{1}{d_{ij}}, i \neq j \\ 0, i = j \end{cases} \tag{17}$$

where $W_{i,j}$ means the traffic distance between two provincial capitals, which can well reflect the relationship between social and economic development between cities.

3. Economic space matrix. Based on the construction of the inverse distance matrix, the economic matrix is defined as follows:

$$W_{i,j} = \begin{cases} \frac{1}{|Y_i - Y_j|}, i \neq j \\ 0, \ i = j \end{cases} \quad (18)$$

4. Nested matrix. The nested matrix organically combines the reverse distance space matrix and the economic space weight matrix, which is specifically expressed as follows:

$$W = \alpha W_{eco} + \beta W_{dis} \quad (19)$$

where $W_{eco}, W_{dis}, \alpha W_{eco}, \beta W_{dis}, \alpha, \beta$, is the economic matrix, which represents the geographical matrix, which is the specific gravity, and the model fit reaches the optimal state when 0.5 is taken by the experiment.

Spatial correlation test method. To investigate the spatial interaction and spillover effect of population aging on high-quality economic development, the global Moran's I index is used to conduct the spatial correlation test. The calculation formula is as follows:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}(Y_{it} - \overline{Y})(Y_{jt} - \overline{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \quad (20)$$

where $w_{i,j}$, $\overline{Y}$, Y_{it}, Y_{jt}—weight matrix defined above, as the mean of the development level, is the development level in the t-year of i and j provinces, respectively.

The value range of Moran's I index is [−1,1]. If the index is positive, there is a positive spatial correlation. Otherwise, there is a negative spatial correlation.

Descriptive Statistics

The analysis of the descriptive statistical results of all variables (Table 2) shows that the maximum value of the index of China's economic high-quality development level is 0.8, the minimum value is 0.097, and the average value is 0.213, indicating that the level of high-quality development of China's economy shows obvious differences. The maximum value of population aging is 0.163, the minimum value is 0.05, and the average value is 0.103, indicating that China's aging is more serious.

The maximum value of per capita GDP is 12.008, the minimum value is 9.108, and the average is 10.826. This could indicate that China's economy has achieved rapid development and that people's living standards have improved. The average industrial structure is 0.478, indicating that the tertiary industry develops faster and accounts for a relatively high proportion, and the structure of the primary, secondary and tertiary industries is more reasonable. Government support (average value—0.299) shows that the Chinese government plays an important role in financial support. The average value of the marketization index is 6.633, indicating that China's marketization process has made significant progress. The maximum value of urbanization is 0.896, the minimum value is 0.338, and the average value is 0.125. The gap between the maximum and the minimum values is large, and the average value is low. This indicates that China's urbanization has obvious regional differences, and the overall urbanization needs to be further improved. The openness of the economy is mainly manifested in China's foreign economic activities, and engaging in foreign trade and investment is conducive to promoting HQED. The maximum value of innovation is 8.42 times higher than the minimum value, indicating that China's technological innovation level needs to continue to improve, and the differences between regions are obvious. The maximum value of the elderly population dependency ratio is 0.238, the minimum value is 0.07, and the average value is 0.141, indicating that the support of China's elderly population is relatively high, and the degree of aging is increasing.

Table 2. Descriptive Statistics.

Variable	Obs	Mean	Std	Min	Max
HQED	248	0.213	0.140	0.097	0.800
Aging	248	0.103	0.023	0.050	0.163
Pgdp	248	10.826	0.434	9.108	12.008
Str	248	0.478	0.093	0.309	0.835
Gov	248	0.299	0.212	0.120	1.354
Mar	248	6.633	2.283	−1.42	11.4
Urb	248	0.572	0.129	0.228	0.896
Open	248	24.409	28.868	0.001	182.374
Inn	248	0.273	0.162	0.110	0.926
Old	248	0.141	0.034	0.07	0.238

Results

The calculated values of the Local Moran Index HQED for 2012 to 2019 are shown in Table 3.

According to Table 2, the Moran's I values of HQED in 31 provinces in China were all greater than 0, and they passed the 1% significance test, indicating that there are certain spatial cluster distribution characteristics. To further explore the local correlations, Moran's I index scatter plots were generated for the HQED of 31 provinces in China in 2012, 2014, 2018 and 2019 (Figure 1).

The HQED index of 31 provinces in China is in the first quadrant. This means that not only is the quality of its own economic development relatively high, but the quality of its surrounding areas is also relatively high, showing a

Table 3. The Local Moran Index for HQED.

Year	W1		W2		W3		W4	
	Moran's I	*p* value	Moran's I	*p* value	Moran's I	*p* value	Moran's I	*p* value
2012	0.378	.000	0.185	.047	0.025	.071	0.357	.000
2013	0.366	.000	0.194	.039	0.026	.065	0.347	.000
2014	0.371	.000	0.168	.070	0.027	.062	0.349	.000
2015	0.346	.000	0.163	.071	0.029	.052	0.318	.000
2016	0.236	.000	0.143	.104	0.026	.061	0.295	.000
2017	0.330	.000	0.163	.075	0.039	.026	0.296	.000
2018	0.304	.000	0.135	.100	0.024	.057	0.268	.000
2019	0.286	.000	0.138	.092	0.027	.042	0.254	.000

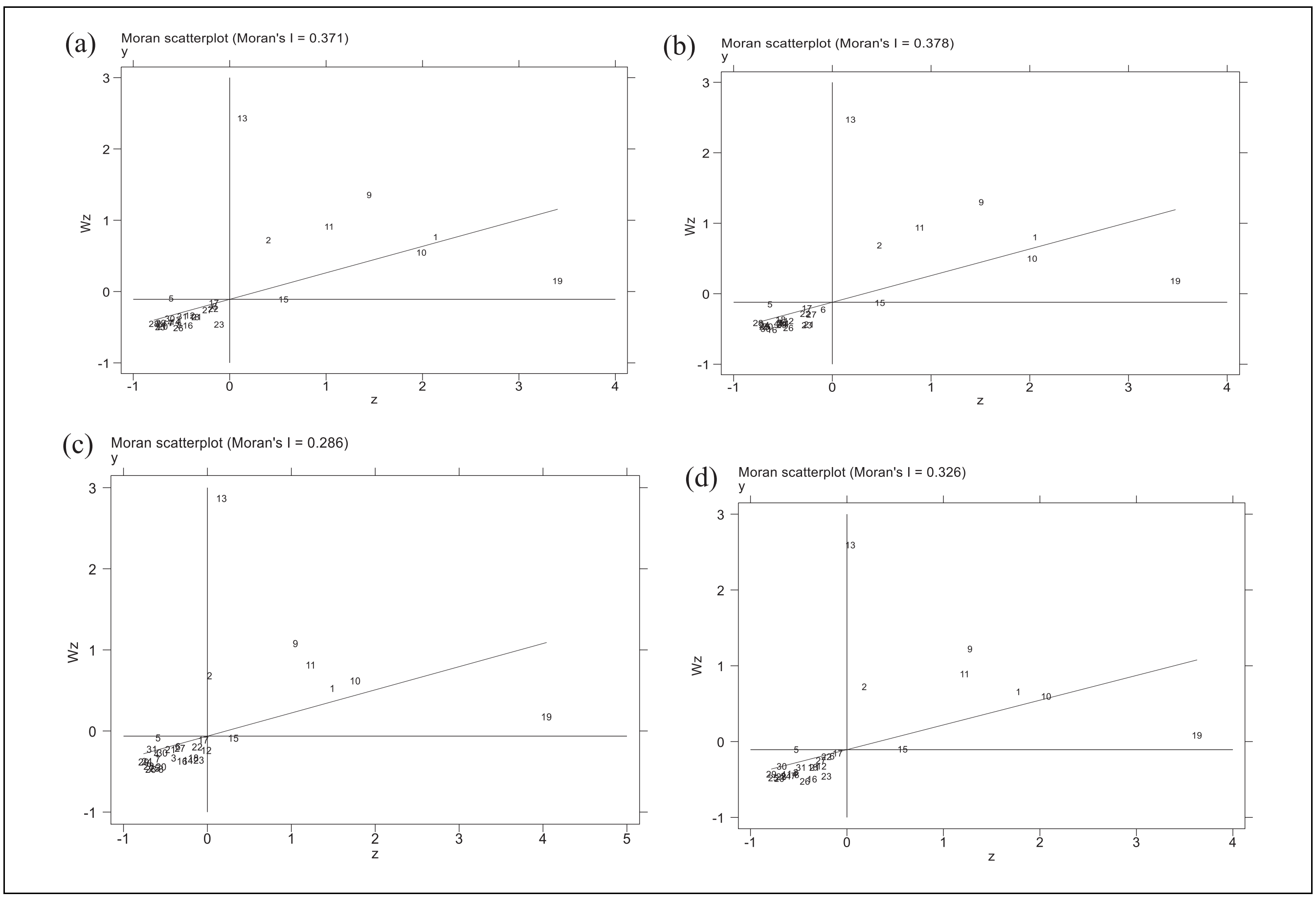

Figure 1. Global Moran map of China's high-quality economic development: (a) 2012, (b) 2014, (c) 2016, and (d) 2019.

"high-high" agglomeration (H-H). Most of the third quadrant is the less developed western areas, showing a distribution trend of "low-low" agglomeration (L-L).

Spatial measurement analysis is applied to verify the accuracy of the above model setting, performing the LM and LR tests (Table 4). The spatial lag and error models pass the 1% significance test, and the spatial Durbin model cannot be reduced to the spatial and error models. Finally, the Hausman test yields 46.94 and passes the test at the 1% significance level, indicating that the best fixed effect is chosen. Thus, the final model identified is the fixed effect of the spatial Durbin model.

In the next step, SAR, SEM and SDM are constructed. According to the regression results in Table 5,

Table 4. The Suitability Test of the Spatial Measurement Model.

Correlation test		WI	*p* value
Spatial error:	LM_error	45.855	.000
	Robust LM_error	33.732	.000
Spatial lag:	LM_lag	12.253	.000
	Robust LM_lag	8.132	.052
LR	SDM-SAR	34.25	.000
	SDM-SEM	34.40	.000
Hausman test		46.94	.000

Table 5. The Regression Results of the Three Different Models.

Variable	Model (9) SAR	Model (10) SEM	Model (12) SDM
Aging	0.161	0.155	0.386**
	0.1518	0.1519	0.1510
Pgdp	0.0094*	0.0093*	0.0085*
	0.0056	0.0057	0.0043
Str	0.0606	0.0628	0.0218**
	0.0459	0.0466	0.0077
Gov	0.0871*	0.0871*	0.0794*
	0.0486	0.0488	0.0467
Mar	0.0068***	0.0067**	0.00447*
	0.0026	0.0027	0.0026
Urb	0.585***	0.593***	0.556***
	0.0948	0.0931	0.1108
Open	0.0004***	0.0004***	0.0005***
	0.0001	0.0001	0.0001
W*Aging			–0.765*
			0.4473
W*Pgdp			0.0387**
			0.0140
W*Str			–0.238*
			0.1394
W*Gov			–0.220
			0.1600
W*Mar			0.0238***
			0.0067
W*Urb			0.369
			0.2686
W*Open			0.3220***
			0.120
R-squared	0.5115	0.5075	0.9821
Log-L	701.2459	701.1697	714.4245
AIC	−1384.5	−1384.3	−1404.7
BIC	−1352.9	−1352.7	−1348.5
N	248	248	248

Note. *, **, *** indicate significance tests of 10%, 5%, and 1%, respectively.

the goodness of fit for SDM is 0.9821, the best fit in each model, and the Log-L value is 714.4245, which was higher than the other models, and the coefficients of each variable are significant. Therefore, it is reasonable to choose a fixed-effect spatial Durbin model to analyze the impact of population aging on HQED. According to the regression results of the SDM, the index of population aging is 0.386 (statistical significance 1%). The results indicate that population aging has a significant effect on HQED and further demonstrate Hypothesis 1.

In the SDM, for regional economic development, the regression coefficient is 0.0085 and significant at the 10% level. It shows that growth of the economic development by 1 point improves the economic quality by 0.0085. In addition, increasing economic development by 1 point contributes to surrounding economic development by 0.0387 (with a significance level of 5%). The regression coefficient for Str and HQED is positive (5% significance level). Thus, improving Strs provokes the growth of HQED by 0.0218. However, the growth of surrounding areas of Str provokes the decline of HQED by 0.238.

The spatial Durbin model explains the spatial economic correlation between provinces, and the parameter estimation results cannot directly reflect the direct effect and spatial spillover effect. Le and Pace (2009) proposes a partial differential method to check the influence of their variables on HQES coefficient decomposition into direct, indirect, and total effects. The empirical results (Table 6) show that population aging has a direct positive effect on HQED (5% significance level). At the same time, the indirect effect of population aging is negative (10% significance level) on regional economic development. This means that aging restricts the economic growth of the surrounding areas.

All analyzed provinces (31) are divided into eastern, central and western regions. The findings of the regional heterogeneity test confirm that population aging has significant regional heterogeneity on HQED (Table 7).

According to the regression of Table 7 results, the eastern region and the central region of the population aging level will significantly promote the HQED, and the HQED of the eastern region is greater than that of the central region. This could be explained by the fact that the eastern region is a more developed province and has more population inflow. The eastern region has a lower degree of population aging than the western region. Furthermore, the economic development of the eastern region is higher than the development level of China (X. Xie & Zhu, 2020). The impact of population aging on the HQED level in the western region is negative and has a significance level of 5%.

To ensure the robustness of the study results, two methods are used to test them. First, the adjacency space matrix (W2), geographic distance weight matrix (W3), and economic geographic nested matrix (W4) are used; second, the core explanatory variables Old are replaced (Zhao et al., 2018). The robustness of the empirical model (Table 8) is validated by replacing the explained variable and replacing the spatial weight matrix for regression.

Table 6. The Results of Spatial Effect Decomposition.

Variable	Direct effect	Indirect effect	Total effect
Aging	0.399** (0.1563)	−0.773* 0.4213	−0.375 (0.4545)
Pgdp	0.0079 (0.0052)	0.0388* (0.0229)	0.0467** (0.0234)
Str	0.0280 (0.0458)	−0.221* (0.1320)	−0.193 (0.1449)
Gov	0.0807* (0.0461)	−0.224 (0.1491)	−0.143 (0.1616)
Mar	0.0042 (0.0026)	0.0232*** (0.0067)	0.0274*** (0.0064)
Urb	0.562*** (0.1123)	0.296 (0.2508)	0.858*** (0.2320)
Open	0.0005*** (0.0001)	−0.0001 (0.0002)	0.0003** (0.0002)
Individual fixed	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes
N	248	248	248

Note. *, **, *** indicate significance tests of 10%, 5%, and 1%, respectively.

Table 7. Test of Regional Heterogeneity.

Variable	East	Middle	West
Aging	1.661* (0.9717)	0.140* (0.0831)	−0.631** (0.2506)
W*Aging	−0.681 (0.6413)	2.792* (1.5832)	−0.343 (0.018)
Direct	0.135*** (0.031)	1.820* (1.0807)	0.702*** (0.2530)
Indirect	−0.687 (0.233)	3.318 (2.2259)	−0.478 (0.4828)
Total	−0.553 (0.9233)	5.138* (2.9323)	0.223 (0.5461)
_cons	Yes	Yes	Yes

Note. *, **, *** indicate significance tests of 10%, 5%, and 1%, respectively.

Table 8. The Results of Robustness Test.

Variable	W2	W3	W4	HQED
Old				−0.202**
				0.0936
Aging	0.303*	0.358**	0.372**	0.0185***
	0.1581	0.1585	0.1529	0.0053
Pgdp	0.0089	0.0118*	0.0096*	0.0288
	0.0058	0.0064	0.0056	0.0479
Str	0.0996**	0.0273	0.0398	0.0833*
	0.0476	0.0512	0.0492	0.0465
Gov	0.107**	0.153***	0.0746	0.0042
	0.0530	0.0578	0.0484	0.0026
Mar	0.0045*	0.0060**	0.0052*	0.523***
	0.0026	0.0025	0.0027	0.1103
Urb	0.436***	0.520***	0.624***	0.0005***
	0.1042	0.1026	0.1172	0.000
Open	0.0005***	0.0005***	0.0004***	0.202**
	0.000	0.000	0.000	0.0936
Individual fixed	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes
N	248	248	248	248

Note. *, **, *** indicate significance tests of 10%, 5%, and 1%, respectively.

Under the three spatial weights, the impact of population aging on HQED is significantly positive, which confirms the population aging effects on HQED, along with the abovementioned results. Changing the core explanatory variables, the impact of the aging population on the influence of HQED also has a negative correlation (5% significance level). Thus, despite the observed spatial structure, all coefficients of aging have a positive effect. In general, it confirms the hypothesis on populating aging impact on HQED unrelate on its spatial structure.

To verify the intermediary effect of technological innovation in population aging on HQED, the step-by-step regression method is adopted to explore the intermediary effect of technological innovation in the link between population aging and HQED. The results of the regression analysis are shown in Table 9.

In Table 9, model 13 reveals the impact of population aging on HQED, according to Hypothesis 1. Model 14 demonstrates the output of the relationship between technological innovation and population aging. Population aging positively affects technological innovation at the 1% significance level, which supports Hypothesis 2. The results of testing Model 13 show that the aging population suppresses HQED at the significance level of 1%. Moreover, technological innovation also has a significant effect, in line with Hypothesis 3. In addition, the elderly population is a basis of economic growth; however, they

Table 9. Results of the Mediation Effect Regression.

Variable	Model (13) HQED	Model (14) Inn	Model (15) HQED
Aging	0.846**	1.425***	–1.306***
	0.3786	0.0190	0.2705
Pgdp		0.0038***	0.0933***
		0.0013	0.0190
Str		0.0197***	0.104
		0.0051	0.0800
Gov		–0.0054*	0.0205
		0.0028	0.0415
Mar		0.0009***	0.0380***
		0.0004	0.0053
Urb		–0.0743***	–0.526***
		0.0060	0.0946
Open		0.0012***	0.0022***
		0.000	0.0003
Inn			–0.965***
			0.1791
_cons	0.126***	–0.0054***	0.145**
	0.0399	0.0020	0.0679
Controls	No	Yes	Yes
Individual fixed	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes
N	248	248	248

Note. *, **, *** indicate significance tests of 10%, 5%, and 1%, respectively.

cannot use technological innovation in an effective way. The negative effect of technological innovations on HQED is explained. It is proven that a nonlinear effect could exist between the analyzed variables.

Discussion

The findings of the SDM show that regional economic development is conducive to qualitive and surrounding economic development by 0.0085 and by 0.0387, respectively. It should be noted that these results are coherent with the results of Zhang et al. (2021). In addition, improving the industrial structure leads to an increase in HQED by 0.0218. At the same time, as in the study (Lande, 1994), the growth of surrounding areas of industrial structure by 1 point decreases the HQED by 0.238. Government financial investment positively affects HQED. Thus, the growth of government investment increases the HQED by 0.0794 (10% significance level). However, government investment in the regions negatively affects HQED, which is consistent with the findings of C. Chen et al. (2017). The marketization level plays a significant role in promoting HQED. It is positively correlated with the HQED of this region and the neighboring regions (J. H. Li, 2012).

The urbanization process and economic quality development are positively related to each other. Urbanization means the accumulation and agglomeration and sharing of knowledge and technology spillover effects. Thus, the findings confirm that urbanization promotes the HWED of the regions and adjacent areas (Turok & McGranahan, 2013). Economic openness is the key dimension for achieving HQED. The regression coefficient of this region and neighboring regions passes the test of 1%, indicating that the level of opening up can promote HQED, which is also proven by C. Ali and Menglan (2019).

It should be noted that the results of spatial effect decomposition are similar to the findings obtained by Cuaresma et al. (2014). Thus, population aging has a direct positive effect on HQED. In the western region, the impact of population aging on the HQED level is negative. This is because the population flow in the western region is mostly provincial flow, with slow economic development and backward technological adjustment. In the western region, the degree of population aging has a direct significant effect on HQED. This result shows that the population aging effect on HQED has an inhibitory effect on nearby areas because the western region has more minority areas, a sparse economic population, and weak natural and social resource endowments, leading to a low level of economic development (Peng, 2008). In general, the impact of population aging on HQED is also "east–central–west."

Conclusions

The study contributes to the theoretical framework of the analysis of the impact of population aging on HQED and the assessment of the mediating role of innovation in linking the impact of population aging and HQED. First, the study developed an approach for the assessment of HQED based on the entropy method from 2012 to 2019 for 31 Chinese provinces. The empirical results show that population aging significantly affects HQED and has regional heterogeneity with a significant and positive correlation for the eastern and central regions and a negative correlation for the western regions. Second, both from the theoretical logic and through the empirical test, it verifies that population aging can significantly improve HQED through the intermediary variable of technological innovation, but there is still a negative correlation with the western region.

Considering the obtained finding, the following policy recommendation could be:

1. With the deepening of the aging population, it is necessary to establish a multilevel old-age security system, steadily promote the overall construction of provincial and national endowment insurance, and reduce the cost of overall planning and coordination.

2. China could accelerate the formation of an old-age security system for urban and rural laborers, encourage the free flow of comprehensive talent across various regions, and rely on demographic dividends to drive technological innovation (Czyżewski & Polcyn, 2016; Gallo et al., 2019; Rosokhata et al., 2022).
3. It is necessary to promote the policy of delaying retirement, appropriately promote the construction of the second and third pillar pension systems and improve the rights and interests of individual pension security.
4. The Chinese government should increase investment in education for the elderly and promote technological innovation and development by improving the quality of the elderly population (Shkarlet et al., 2019; Kuzior, 2022). Based on fully studying the wealth status and risk preference of elderly individuals, the supply of pension financial products should be increased to form a multilevel and differentiated pension financial product system.
5. Government spending on technological innovation, relevant supporting policies, and supporting scientific and technological innovation stimulate HQED. It is necessary to provide the training of high and new technology personnel to improve the system and mechanism for the development and promotion of personnel and accelerate team development and innovation level (Ginevičius, Szczepańska-Woszczyna et al., 2021).
6. The Chinese government should implement a series of preferential tax policies, including increasing revenue and reducing taxes for science and technology enterprises, to encourage talent and enterprises to increase investment in scientific research and foster and strengthen new drivers of growth.

Despite the valuable findings, this study has a few limitations. Thus, it is necessary to extend the object of investigations and focus not only on China but also on other Asian countries. It allows obtaining more reliable results and comparing countries. In addition, Industry 4.0 catalysts the penetration of digital technologies among all sectors and spheres (Kuzior, 2022; Miskiewicz, 2020, 2022), which should be considered in further investigations. Furthermore, HQED, innovation development and overcoming issues from population aging depend on the efficiency of government regulation, corruption, transparency and accountability, and rule of law. In this case, future analysis should consider the quality of governance, which justifies the practical recommendation on policy for overcoming issues from population aging within attaining HQED due to extending innovations.

Author Contributions

Conceptualization, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; methodology, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; formal analysis, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; investigation, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; writing—original draft preparation, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; writing—review and editing, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko; visualization, Wenqun Gao, Yang Chen, Shaorui Xu, Oleksii Lyulyov, Tetyana Pimonenko. All authors have read and agreed to the published version of the manuscript.

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ORCID iDs

Yang Chen https://orcid.org/0000-0002-4801-4036
Tetyana Pimonenko https://orcid.org/0000-0001-6442-3684

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