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Dynamic Analysis of the Effects of Aging on China's Sustainable Economic Growth

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Abstract: China's aging population has deeply affected the sustainable development of the Chinese economy. Based on the provincial panel data of China's population and economic indicators from 2000 to 2020, this paper develops a panel vector autoregressive model to analyze the effect of China's aging population on economic growth under the paths of household consumption and national savings, respectively. The results show that an aging population inhibits household consumption and promotes national saving, which has both direct and indirect effects on economic growth. In particular, an aging population is not conducive to sustainable economic development in the context of China's slow population growth over the past three years and the contraction of the global economy due to the COVID-19 pandemic. In accordance with the empirical results, this paper puts forward corresponding policy recommendations, as follows: improve the pension security system; develop the silver-hair industry; expand domestic demand in China; encourage fertility; and increase human capital investment to provide an impetus for sustainable economic development.

Keywords: aging; panel vector autoregressive model; expanding domestic demand; increasing consumption; sustainable economic development



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1. Introduction

China's fertility rate has been declining in recent decades due to the adoption of the family planning policy and the country's accelerated economic growth. In parallel, as living standards have improved and medical technology has advanced, the average person's life expectancy has increased dramatically, leading to considerable changes in the age structure of the Chinese population. China has quickly acceded to the aging society since the turn of the century. According to figures from China's fifth population census, there were 130 million people in China who were 60 years of age or older, making up 10.2% of the country's total population, and there were 88.11 million people who were 65 years of age or older, constituting 6.96% of the population overall [1]. China started to transition towards an aging society, according to the United Nations report "The Aging of Populations and its economic and social implications" [2]. The proportion of people 65 and older in the population in 2010 was 8.9%, which was greater than the average global aging rate for the same period and made it the nation with the highest senior population in the world [1]. By the seventh population census in 2020, China had 190.6 million people aged 65 and over, or 13.5% of the total population, and 264 million people aged 60 and over, or 18.7% of the total population, further highlighting the extent of population aging [3]. The aging process in China is marked by three distinguishing features in comparison with other nations. First, the pace of the aging process in China is the most rapid. Second, China is home to the world's largest elderly population, a trend likely to remain for an extended duration. Lastly, the aging problem in China is characterized by growing old before getting rich, i.e., the rate of aging outpaces that of per capita income growth.

The impact of an aging population on economic development is most evident in the labor supply shock that results from the disappearance of a certain demographic. An

aging population will also have a more direct negative impact on demand factors, which may reduce the amount of consumption and the propensity to consume as a result of three effects [4]. The first concerns the impact of the population size. A reduction in population growth rate implies a deceleration in consumption rate; indeed, if all other factors are equal, a negative population growth rate corresponds with a decline in the number of consumers. The second effect concerns age and societal structures. As the population continues to age, the elderly consumes less and the heavy burden of social security payments on the employed will decrease consumption capacity at the macro level; thus, the propensity of employed people to consume will decrease. The third concerns the effect of income distribution. A greater proportion of national income is captured by higher income groups with a low propensity to consume and high propensity to save when the income gap is large [5]. However, if an aging population can effectively force technology to upgrade and improve human capital investment, it can alleviate the pressure of a potential declining growth rate and promote industrial upgrades [6]. An aging population will also result in industrial restructuring due to changes in consumption propensity, consumption preference, and factor endowment. The short- and long-term effects of an aging population on economic growth, as well as the orientation of these effects, are therefore difficult to summarize succinctly.

Based on the abovementioned factors, in light of the vast differences between aging populations and economic development in different regions of China, this paper selects panel data from 31 provinces of China during 2000–2020, and it employs a panel vector autoregressive model to conduct an empirical analysis of the effect of an aging population on economic growth in China via an examination of consumption and savings. It is of the utmost importance to examine the impact of an aging population on economic growth and derive appropriate preventive conclusions and recommendations for sustaining the Chinese economy's sustainable development.

2. Literature Review

As the Chinese population ages, China's economic and social development is necessarily affected by a series of profound and long-lasting effects. The characteristics of China's elderly population (such as the fact that this is a large demographic, it is aging quickly, and there are great regional differences between aging populations), as well as the social problems they bring, have been concerning for the academic community. Some scholars believe that an aging population will inhibit economic growth [7]. Miri's research suggests that an increase in the proportion of people over the age of 64 reduces the marginal propensity to save, which could have a negative impact on economic growth. Mason also found that an aging population will have an adverse effect on sustainable economic development in Asia [8]. Maestas analyzed the impact of an aging population on GDP growth per capita using data from 1980 to 2010. They used varied predetermined components of aging populations across states and found that an aging population is expected to slow down US economic growth due to less employment and labor productivity growth [9]. Yang used data from six central provinces in China from 2011 to 2020, and they developed fixed-effects and mediating-effects models to show that an aging population suppresses economic growth by reducing effective labor input, residential consumption levels, and urbanization rates [10]. Huang's study, based on quarterly data from Taiwan from 1981 to 2017, found that an increase in the old-age dependency ratio has a significantly negative effect on the GDP growth rate [11]. Calvo-Sotomayor used panel data from 24 countries between 1983 and 2014 to demonstrate that Europe's aging workforce prompted a decrease in productivity [12].

Although some scholars argue that an aging population may hinder economic growth, there are also scholars who believe it can have a positive impact. Zhao's research, based on a panel of 31 Chinese provinces from 2000 to 2016, found that an aging population played a significant role in boosting China's economic growth since it became an aging society; their findings were obtained with a one-step system GMM estimation method [13]. Quantitative

research results have shown that the impact of an aging population on economic growth is multifaceted; thus, driving the development of silver-hair industries will be conducive for economic growth, and an aging population is beneficial for promoting the development of secondary industries in China [14,15]. Acemoglu and Restrepo also argue that countries experiencing a more rapid aging process have grown more rapidly due to the rapid adoption of automation technologies in these countries [16]. Burtless notes that the increase in the size of the labor force over the age of 60 can have a positive impact on productivity [17]. Huang found that an increasingly aging workforce has significantly and positively impacted productivity; thus, an aging workforce can contribute to economic growth [11]. Additionally, some scholars found that an aging population can lead to an increase in savings; these findings were obtained by constructing a dynamic model that combined a life-cycle model and a Solow growth model. This contradicts the conventional view that an aging population causes a decrease in savings and inhibits economic growth [18].

Other studies have found that the impact of an aging population on economic growth is uncertain. Previous empirical studies examining the overall impact of an aging population on economic growth have often yielded mixed results, as shown in Nagarajan's work [19]. Prettnner's research indicates that an aging population does not necessarily hinder technological progress and sustainable economic growth; this was established through an endogenous technological change model [20]. Similarly, Lee used a partial adjustment model in a panel framework and a dataset for 80 countries from 1960 to 2005, and they found no evidence to suggest that an aging population hinders economic growth [21]. Börsch-Supan and Weiss suggested that although aging employees tend to commit more mistakes, there is no visible decline in their productivity [22].

In sum, the impact of an aging population on economic growth is still a topic of debate and requires further research. Due to the research methodology, model construction, and variable selection, the impact on economic growth is still inconclusive. In this paper, we will set up a panel vector autoregressive model (PVAR) using provincial panel data concerning the elderly dependency ratio, household consumption expenditure, national saving rate, and per capita gross regional product in China from 2000 to 2020. Moreover, we will use the impulse–response function and variance decomposition to empirically analyze the impact of an aging population on economic growth based on household consumption and national savings, respectively. Furthermore, we will propose corresponding policy recommendations to cope with the problems that may result from an aging population, thus contributing to sustainable economic development.

3. Materials and Methods

3.1. Data Sources and Processing

Considering the availability of data and the process of China's demographic development, China has been an aging society since 2000; thus, the data were selected between 2000 and 2020. The data were mainly obtained from the China Population and Employment Statistical Yearbook and the China Statistical Yearbook from 2001 to 2021. Moreover, the old-age dependency ratio, per capita regional GDP, regional per capita consumption expenditure, and regional final consumption rate of 31 provinces (autonomous regions and municipalities directly under the Central Government's control) from 2000 to 2020 were selected (excluding data from Hong Kong, Macao, and Taiwan).

From an economic perspective, this paper uses the regional old-age dependency ratio (*odep*) to reflect the aging of the region's population; it indicates whether the economic burden is caused by the aging of the regional population. The logarithm of regional gross domestic product per capita (*lnpgdp*) reflects the economic growth of the region. The logarithm of regional consumption expenditure per capita (*lnpcons*) was used to reflect the regional consumption level of residents; this directly reflects the consumption ability and consumption level of residents. The national savings rate (*sav*) was used to reflect the regional national savings level, which is a fundamental factor affecting investments and economic growth. As there are no data concerning the national savings rate

in China, this paper selects 1 minus the final consumption rate to approximate the regional national savings rate, and thus, the specific calculation formula is: national savings rate = 1-final consumption rate, i.e., $(1-\text{final consumption}/\text{GDP}) \times 100 = (1-\text{resident final consumption}/\text{GDP}-\text{government final consumption}/\text{GDP}) \times 100$. Table 1 provides descriptive statistics for the four primary variables. As shown in the data below, the overall mean for the aging population, the logarithm of per capita consumption expenditure, logarithm of per capita GDP, and savings rate for each province are 12.97, 9.01, 10.12, and 46.75, respectively. The total variance of the aging population is 3.44, thus indicating that the degree to which a population ages varies substantially across provinces and years. Finally, the specific outcomes of other variables are displayed in Table 1 below.

Table 1. Descriptive statistics. This table gives the basic statistics for the four variables mentioned above.

Variable		Average	Standard Deviation	Minimum	Maximum	Observations
odep	overall		3.4423	6.1453	25.4800	N = 651
	between	12.9727	2.3168	8.4167	17.4143	n = 31
	within		2.5781	5.4688	22.2827	T = 21
lnpcons	overall		0.7541	7.5191	10.7278	N = 651
	between	9.0113	0.3540	8.4693	9.9369	n = 31
	within		0.6687	7.7779	10.0745	T = 21
lnpgdp	overall		0.8505	7.9226	12.0086	N = 434
	between	10.1205	0.4411	9.4079	11.2146	n = 31
	within		0.7312	8.6278	11.4568	T = 21
sav	overall		9.2837	8.9000	63.9300	N = 434
	between	46.7483	7.4362	29.9274	56.2757	n = 31
	within		5.7089	24.5984	65.3210	T = 21

3.2. Model Construction

This paper empirically analyzes the impact of an aging population on consumption and economic growth and the impact of an aging population on savings and economic growth by constructing a panel VAR model (PVAR) [23]. Holtz-Eakin proposed a vector autoregressive model (PVAR) for panel data that inherits many of the advantages of the VAR model in that it treats all the variables in the system as endogenous. Moreover, it allows the calculation of an orthogonalized impulse–response function to analyze the extent to which one endogenous variable affects other endogenous variables; thus, it inherits the advantages of panel data in that it covers individual variability and common shocks across cross-sections by taking into account the individual and time effects, respectively [24].

The PVAR model in this paper is as follows:

$$y_{it} = \alpha_i + \beta_i + \sum_{j=1}^p \beta_p y_{i,t-p} + \varepsilon_{it}, \quad i = 1, 2, \dots, 31 \text{ and } t = 2000, 2001, \dots, 2020 \quad (1)$$

when considering aging-consumption-economic growth, y_{it} is a vector of three variables $y_{it} = \{\lnpgdp, \lnpcons, odep\}$. When considering aging-national savings-economic growth, y_{it} is a vector of three variables $y_{it} = \{\lnpgdp, sav, odep\}$. p is the lagging order. To indicate individual effects, α_i was introduced, thus allowing for geographical variation in the variables. By adding β_t , which is the time effect, it is possible to indicate internal trends in system variables. β_p is the 3×3 dimensional coefficient matrix, and ε_{it} is a random perturbation term that follows a normal distribution.

In this paper, the establishment of a panel VAR model consists of four main steps: (1) the selection of the lagged order of the PVAR model; (2) the estimation of the panel data using the panel generalized moment estimation (GMM) method to illustrate the regression relationship between variables; (3) the estimation of the impulse–response function to reflect the impact of shocks on each variable and the effect that these shocks have on each variable through dynamic impulse–response plots; and (4) the variance decomposition of

the error term to further illustrate the level of influence that the influencing factors have on the error term [25].

The relationship between population structure, saving rate, and economic growth has also been studied in domestic literature [26] using the PVAR model, but several existing problems have been improved in this paper. Firstly, when establishing the PVAR model, the lag-1 order may not be optimal; therefore, this paper uses AIC, BIC, and HQIC statistics to select the optimal lag order, which is lag-2 according to the results. Moreover, the existing literature does not analyze the contribution of structural shocks to changes in endogenous variables by variance decomposition. Lastly, Dong and Zhao [26] took the 5-year average of variables as a sample, which led to information loss. The short sample time series limits the estimation of multi-order lagged terms. In addition, this paper analyzes the impact of population aging on the economy using residential consumption and national savings as indicators. The former tends to indicate the micro-foundation of individual and household behaviors, whereas the latter is the macro-foundation at the national level.

4. Results

4.1. Unit Root Test and Cointegration Test

Although the panel data of the PVAR model has reduced the correlation between variables, its timing characteristics determine the possibility of non-stationary stochastic fluctuations; therefore, a unit root test for serial smoothness is performed before establishing the PVAR model. The results are shown in Table 2.

Table 2. Results of the unit root test. The table shows the statistical results of the unit root test for the four variables and their difference sequences by using three test methods.

	LLC	IPS	ADF–Fisher
<i>odep</i>	3.6369 (0.9999)	6.8329 (1.0000)	83.4232 ** (0.0362)
<i>lnpgdp</i>	−12.7862 *** (0.0000)	−4.7319 *** (0.0000)	44.8439 (0.9505)
<i>lnpcons</i>	−10.7704 *** (0.0000)	0.4797 (0.6842)	41.9374 (0.9763)
<i>sav</i>	−4.3464 *** (0.0000)	−0.5188 (0.3019)	79.8086 * (0.0635)
$\Delta odep$	−6.6857 *** (0.0000)	−12.2327 *** (0.0000)	529.6420 *** (0.0000)
$\Delta(\Delta lnpgdp)$	−21.6703 *** (0.0000)	−12.6715 *** (0.0000)	416.1127 *** (0.0000)
$\Delta(\Delta lnpcons)$	−7.9583 *** (0.0000)	−14.7548 *** (0.0000)	509.1680 *** (0.0000)
Δsav	−6.4387 *** (0.0000)	−9.1955 *** (0.0000)	246.1512 *** (0.0000)

Note: ***, **, * denote rejection of the original hypothesis of the existence of unit root at 1%, 5%, and 10% significant levels, respectively; Δ denotes first difference of the series.

At a significance level of 5%, the variables *odep*, *lnpcons*, *lnpgdp*, and *sav* are all non-stationary series. After the first difference, $\Delta odep$ and Δsav are stationary time series; after the second difference, $\Delta(\Delta lnpgdp)$ and $\Delta(\Delta lnpcons)$ are stationary, that is, *odep*, *lnpgdp*, *lnpcons*, and *sav* are all integrated of order 2, that is, I(2). In cases where integration of order 2 emerges, the cointegration test analysis of variables is carried out to test whether there is a long-term equilibrium relationship between variables.

In general, the panel data vector autoregressive model (PVAR) is more effective than the panel data vector error correction model (PVEC), and the panel data vector error correction model (PVEC) should be established when there is a cointegration relationship in

the panel data; if there is no cointegration relationship, the panel data vector autoregressive model (PVAR) is more effective [27].

The cointegration test is conducted separately for the two groups formed by the following variables: *lnpgdp*, *odep*, and *lnpcons*; *lnpgdp*, *odep*, and *sav*. This is to test whether there is a cointegration relationship between the two groups of data. This paper adopts the panel cointegration test method, and the results of the group and panel statistics are shown in Tables 3 and 4.

Table 3. Results of the cointegration test of aging-consumption-economic growth.

Standard	Statistics	Z-Value	p-Value
Gt	−0.868	2.727	0.997
Ga	−3.300	2.570	0.995
Pt	−3.222	1.502	0.933
Pa	−2.349	0.170	0.568

Table 4. Results of the cointegration test of aging-savings-economic growth.

Standard	Statistics	Z-Value	p-Value
Gt	−0.434	5.034	1.000
Ga	−0.436	5.486	1.000
Pt	−2.146	2.311	0.990
Pa	−0.314	2.482	0.994

As can be seen from Table 3, the four statistical groups of Gt, Ga, Pt, and Pa are not significant at the 5% significance level, thus indicating that there is no cointegration relationship between the three variables of $\{lnpgdp, lnpcons, odep\}$ (i.e., there is no long-run equilibrium relationship). Similarly, Table 4 shows that there is no cointegration relationship between the three variables $\{lnpgdp, sav, odep\}$.

Therefore, this paper establishes a panel vector autoregressive (PVAR) model to empirically analyze the effects of aging on consumption and economic growth, particularly the effects of aging on savings and economic growth for the two sets of variables $\{lnpgdp, lnpcons, odep\}$ and $\{lnpgdp, sav, odep\}$, using panel data from 31 provinces and cities in China from 2000 to 2020, respectively.

4.2. Selection of Lag Order

In this paper, AIC, BIC, and HQIC statistics are used to determine the optimal autoregressive lag order; the optimal lag order of the model is determined based on the order in which AIC, BIC, or HQIC takes the minimum value. When the three are inconsistent, BIC/HQIC tends to choose the more compact model, whereas AIC tends to choose the more complex model; BIC/HQIC is usually superior to AIC [28]. The results are shown in Tables 5 and 6.

Table 5. Test for lag order selection in the “Aging-Consumption-Economic Growth” panel VAR model.

Lag Order	PVAR (1)	PVAR (2)	PVAR (3)	PVAR (4)
AIC	2.5422	−2.7661	−3.2525 *	−3.0839
BIC	3.3005	−1.9059	−2.2809 *	−1.9899
HQIC	−2.6800	−2.4301	−2.8721 *	−2.6545

Note: * denote the significance of the lag order.

As seen in Table 5, the PVAR model with the three variables, *lnpgdp*, *lnpcons*, and *odep*, provides the lowest AIC, BIC, and HQIC statistics when the lag order of the variables is three; this indicates that the lag order should be selected as three to establish the PVAR (3) model of “aging-consumption-economic growth”. Similarly, we can see from Table 6 that

the PVAR model with the three variables, *lnpgdp*, *sav*, and *odep*, has the lowest statistics for AIC, BIC, and HQIC when the lag order of the variables is three; therefore, the lag order of three was also selected to establish the PVAR model of “aging–savings–economic growth”.

Table 6. Test for lag order selection in the “Aging–Savings–Economic Growth” panel VAR model.

Lag Order	PVAR (1)	PVAR (2)	PVAR (3)	PVAR (4)	PVAR (5)
AIC	9.2665	5.6399	5.4175 *	5.7636	5.8066
BIC	10.0247	6.5001	6.3891 *	6.8576	7.0359
HQIC	9.5619	5.9758	5.7979 *	6.1930	6.2905

Note: * denote the significance of the lag order.

4.3. PVAR Estimation

As the PVAR model contains both time and individual effects, this paper eliminated them before establishing the PVAR model by applying the cross-sectional mean difference to each variable to eliminate the time effect. Then, the forward mean difference was used to eliminate the individual effects (the Helmert process transformation). A bias in coefficient estimation, caused by the time effect and the individual effect, was thus avoided. In this section, the model was estimated using the Generalized Method of Moments (GMM) [29]; this involved using the gross regional product per capita as the dependent variable, and the other variables and their third-order lag were used as independent variables, respectively.

4.3.1. PVAR Estimation of “Aging–Consumption–Economic Growth”

A PVAR model including third-order lags was developed to analyze the dynamic effects of aging on residential consumption and economic growth. Panel data concerning the old-age dependency ratio, log of per capita residential consumption expenditure, and log of per capita gross regional product for 31 provinces in China from 2000 to 2020 were used. The estimated results are shown in Table 7.

Table 7. Results of PVAR estimation of “aging–consumption–economic growth”.

Dependent Variables	h_ <i>lnpgdp</i>		h_ <i>lnpcons</i>		h_ <i>odep</i>	
	b_GMM	t_GMM	b_GMM	t_GMM	b_GMM	t_GMM
L.h_ <i>lnpgdp</i>	1.589	7.92	0.260	1.37	−5.566	−0.87
L.h_ <i>lnpcons</i>	−0.073	−0.91	0.685	7.73	−2.768	−1.26
L.h_ <i>odep</i>	−0.007	−2.88	−0.008	−3.55	0.593	7.21
L2.h_ <i>lnpgdp</i>	−0.568	−3.46	−0.133	−0.92	1.255	0.30
L2.h_ <i>lnpcons</i>	0.102	1.35	0.181	2.69	2.336	0.97
L2.h_ <i>odep</i>	0.000	−0.12	−0.004	−1.82	−0.003	−0.04
L3.h_ <i>lnpgdp</i>	−0.004	−0.04	−0.013	−0.16	2.224	0.87
L3.h_ <i>lnpcons</i>	−0.057	−1.11	−0.045	−0.80	1.845	0.86
L3.h_ <i>odep</i>	−0.004	−1.65	−0.001	−0.24	0.148	1.87

Note: (1) b_GMM denotes GMM estimated coefficient, t_GMM denotes T-statistic; (2) Ln. denotes nth-order lag.

As can be seen from Table 7, the direct relationship between economic growth and aging is not significant when considering household consumption. In terms of the relationship between *lnpgdp* and *odep*, in light of the changes in the old-age dependency ratio, the dynamic response of the logarithm of the per capita regional product was −0.007 in the first phase and 0.0001 and −0.004 in the second and third phases, respectively; however, the coefficients were not significant. This shows that the direct relationship between economic growth and an aging population is not significant.

An aging population will reduce consumption. In terms of the relationship between *lnpcons* and *odep*, in light of changes in the old-age dependency ratio, the dynamic response of the logarithm of per capita household consumption expenditure is negative: −0.008 in the first phase and −0.004 and −0.001 in the second and third phases, respectively. Moreover, the coefficient of the first two phases is significant at a significance level of 5%

and 10%. This indicates that as the population continues to age, residents' consumption will be inhibited, but the effect of this inhibition will gradually decline.

4.3.2. PVAR Estimation of “Aging-Savings-Economic Growth”

A PVAR model including third-order lags was developed to analyze the dynamic effects of aging on national savings and economic growth. Panel data on the old-age dependency ratio, saving rate, and log of per capita gross regional product for 31 provinces in China from 2000 to 2020 were used. The estimated results are shown in Table 8.

Table 8. Results of the PVAR estimation of “aging–savings–economic growth”.

Dependent Variables	h_lnpdp		h_sav		h_odep	
	b_GMM	t_GMM	b_GMM	t_GMM	b_GMM	t_GMM
L.h_lnpdp	1.378	6.40	13.651	0.63	−11.134	−1.56
L.h_sav	−0.002	−1.53	0.858	10.37	−0.026	−0.73
L.h_odep	−0.009	−3.48	0.080	0.38	0.576	6.06
L2.h_lnpdp	−0.425	−2.56	−10.807	−0.70	5.206	1.17
L2.h_sav	0.001	1.21	−0.068	−0.56	−0.027	−1.23
L2.h_odep	−0.001	−0.32	−0.076	−0.56	−0.009	−0.12
L3.h_lnpdp	0.014	0.19	−2.195	−0.44	4.583	1.82
L3.h_sav	−0.000	−0.67	0.045	0.44	−0.016	−0.85
L3.h_odep	0.002	−0.68	0.159	0.77	0.210	2.40

Note: (1) b_GMM denotes GMM estimated coefficient, t_GMM denotes T-statistic; (2) Ln. denotes nth-order lag.

As can be seen from Table 8, the direct relationship between economic growth and aging is not significant when national savings are considered. After the addition of the variable sav, in light of changes in the old-age dependency ratio odep, the dynamic response of the logarithm of per capita regional product (GDP) in the first phase is −0.009, and in the second and third phases, it is 0.001 and 0.002, respectively; however, the coefficients are not significant, thus indicating that the direct relationship between economic growth and an aging population is not significant. These findings are similar to the results concerning household consumption.

The direct relationship between national savings and aging is also not significant. In terms of the relationship between sav and odep, the dynamic response of national savings rate was 0.08 in the first phase, −0.076 in the second phase, and 0.159 in the third phase, thus indicating that an aging population has a certain lagged positive effect on national savings; however, the coefficients in the third phase are not significant. This indicates that as people continue to age, the impact on national savings is not significant.

4.4. Analysis of Impulse–Response Function

To test the dynamic relationship between the variables, this paper uses the impulse–response function to study the effect of endogenous variable shocks on the variables and other endogenous variables. The Cholesky orthogonal decomposition of the impulse–response function is very sensitive to the ranking of the variables, and the change in demographic structure reflects the change in the working population; this leads to changes in the level of per capita income, which, in turn, affects consumption and savings. Conversely, economic growth does not immediately cause changes in the demographic structure, which changes relatively slowly; therefore, in the Cholesky decomposition of the impulse–response function, odep, which represents the demographic variables, is ranked first, followed by lnpdp, the per capita gross regional product, lnpcns, the per capita consumption expenditure, or sav, the national saving rate. The two sets of variables are thus {odep, lnpdp, lnpcns} and {odep, lnpdp, sav}.

In this paper, impulse–response function plots are obtained by giving a standard deviation shock to the variables; this was achieved by using Monte Carlo simulations 500 times, and 95% confidence intervals are given.

4.4.1. Impulse–Response Function Analysis of “Aging–Consumption–Economic Growth”

The impulse–response function plot is shown in Figure 1, which is obtained via a Monte Carlo simulation of the variables $\{odep, lnpgdp, lnpcns\}$; this was achieved using a PVAR model with the old-age dependency ratio, log of per capita gross regional product, and log of per capita consumption expenditure.

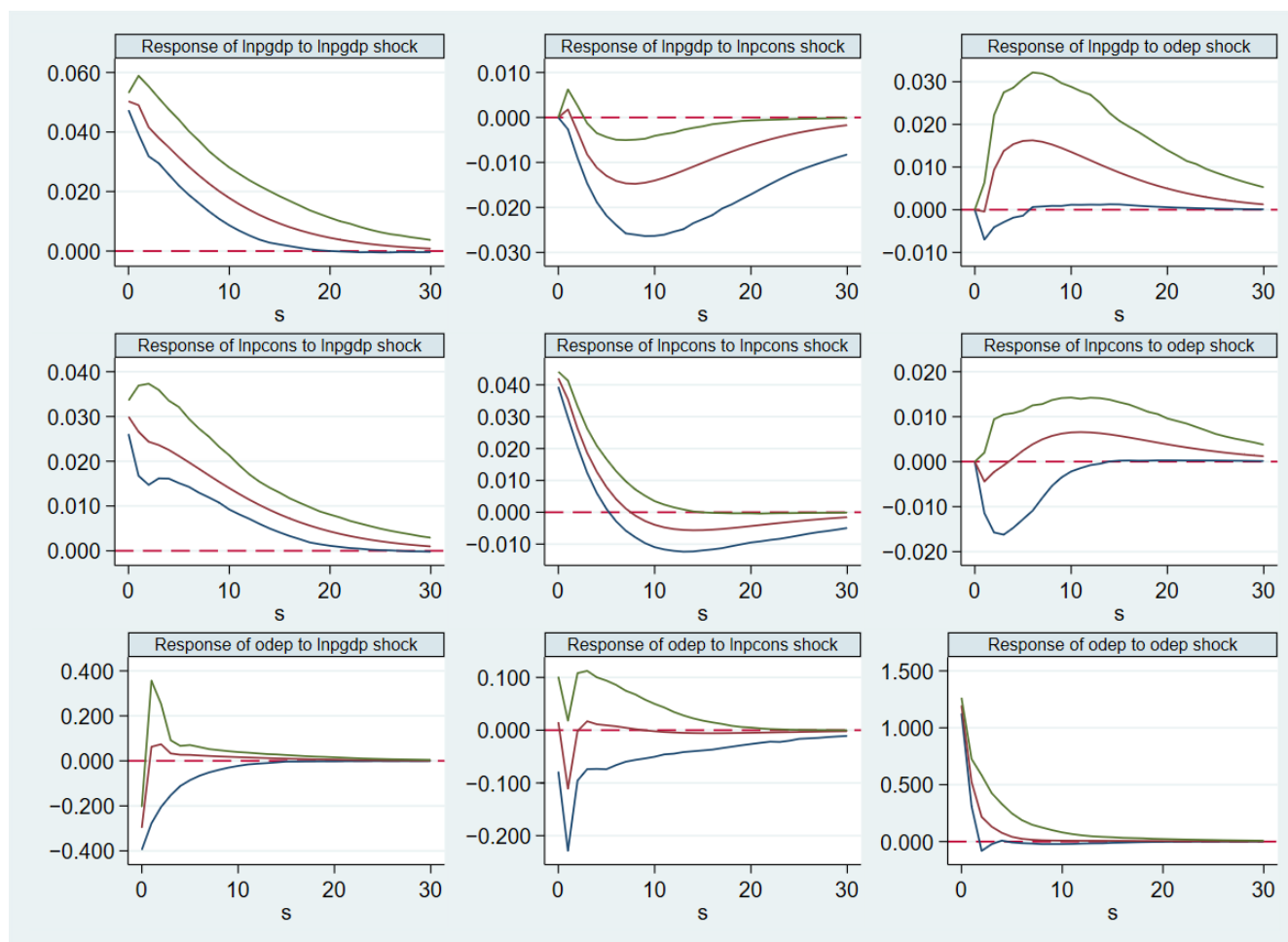


Figure 1. Graph of the impulse–response function of “aging–consumption–economic growth”. This figure shows the impulse effect of each variable on itself and other variables in model “aging–consumption–economic growth”. The red line in the center represents the impulse response function, whereas green and blue lines represent two standard deviation bands.

From Figure 1, the impact of a shock of an orthogonalized innovation, regarding the effect of aging on economic growth, is 0 in the first period; then, for the remaining periods, the value is negative, and the negative effect is more stable, thus indicating that the shock of an aging population has no effect on economic growth in the same period. However, the negative effect of aging on economic growth is persistent and stable, and aging has a dragging effect on economic growth.

The impulse–response function plot of the old-age dependency ratio on the log of per capita consumption expenditure (third row, first column) shows that the impact of an orthogonalized innovation (standard deviation) shock on the degree of aging and on per capita consumption expenditure has been consistently negative, showing a downward and then upward trend; however, the upward response is weaker and still negative, and it finally produces a very small negative effect, thus indicating that the shock of aging has

a continuously negative effect on per capita consumption expenditure in China, to some extent. Nevertheless, the impact of the negative effect gradually becomes weaker.

In addition, considering the indirect path of an aging population $\rightarrow$ consumption level $\rightarrow$ economic growth, the graph showing the impulse–response function of the old-age dependency ratio and the logarithm of per capita consumption expenditure (third row, first column) and the graph showing the impulse–response function of the logarithm of per capita consumption expenditure and the logarithm of per capita regional GDP (second row, third column) show that an orthogonalized innovation, with regard to aging, first has a negative effect on the level of residential consumption, which, in turn, has a negative influence on economic growth. Thus, the indirect path of “aging $\rightarrow$ consumption level $\rightarrow$ economic growth” shows that the negative effect of aging on economic growth is partly due to the transmission of the negative effect of aging on the household consumption level. In conclusion, an aging population has a negative effect on both consumption and economic growth when considering household consumption, and regarding the indirect path of aging $\rightarrow$ consumption level $\rightarrow$ economic growth, aging is not conducive to an increase in consumption level, and thus, it has a negative effect on economic growth.

4.4.2. Impulse–Response Function Analysis of Aging-Savings-Economic Growth

The impulse–response function plot is shown in Figure 2, which is obtained by the Monte Carlo simulation of the variables $\{odep, lngdp, sav\}$ using a PVAR model with the old-age dependency ratio, national savings rate, and log of per capita gross regional product.

As shown in Figure 2, considering national savings and using the impulse–response function plot (second row, first column) of the old-age dependency ratio on the log of per capita regional GDP, it is evident that the impact of an orthogonalized innovation shock, regarding the degree of aging on economic growth, continues to be negative; it is followed by an upward trend, but it remains negative, thus indicating that the shock of an aging population leads to a negative change in economic growth. Nevertheless, the impact of the negative effect gradually becomes weaker.

From the impulse–response function plot concerning the old-age dependency ratio on the national savings rate (third row, first column), it is evident that the impact of an orthogonalized innovation shock, with regard to an aging population, on economic growth is zero in the first period, then it becomes positive before decreasing; this produces a very small negative effect, thus indicating that when facing the shock of an aging population, the national saving rate is not affected in the current period, and it has a positive effect on national savings in the short term. However, aging has a negative effect on national savings in the medium and long term.

In addition, considering the indirect path of aging $\rightarrow$ national savings $\rightarrow$ economic growth, two pairs of impulse–response function plots (the old-age dependency ratio on the national savings rate (third row, first column) and the savings rate on the log of per capita gross regional product (second row, third column)) show that the shock of orthogonalized innovations on the national saving rate leads to a positive change in economic growth, with a clear upward trend, thus indicating that national saving is beneficial to economic growth. Regarding the indirect impact path, an orthogonalized innovation shock, with regard to aging, has a small positive effect on national savings first, and then, to some extent, it has a positive effect on economic growth; therefore, the indirect path of aging $\rightarrow$ national savings $\rightarrow$ economic growth shows that aging has a positive effect on economic growth to some extent, but the overall effect of aging on economic growth is negative, thus indicating that the positive effect of aging on economic growth is small, and an increase in national savings is not enough to directly offset the negative effect of an aging population on economic growth.

In conclusion, regarding the national saving path, aging has a negative effect on economic growth, with an elevated effect on national savings in the short term, followed by a negative effect in the long term; this produces a small positive cumulative effect. In the indirect path of aging $\rightarrow$ national savings $\rightarrow$ economic growth, the small positive effect

concerning national savings is not enough to offset the direct negative effect of aging on economic growth.

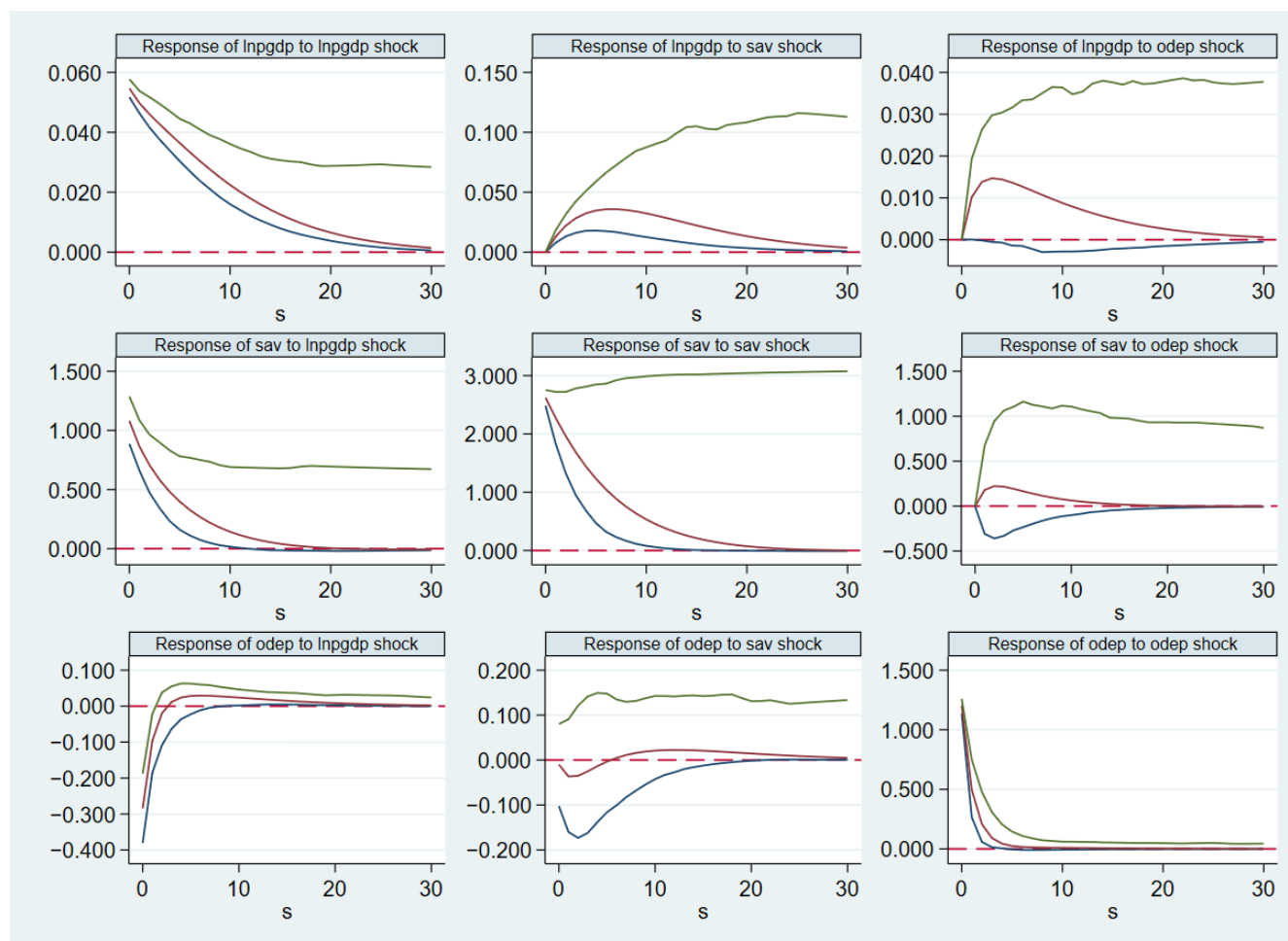


Figure 2. Graph showing the impulse–response function of “aging–savings–economic growth”. This figure shows the impulsive effect of each variable on itself and other variables in the model “aging–savings–economic growth”. The red line in the center represents the impulse response function, whereas green and blue lines represent two standard deviation bands.

4.5. Analysis of Variance Decomposition

In order to examine the degree of interaction between aging, economic growth, residential consumption, and national savings more precisely, this paper obtains variance decomposition via a Monte Carlo simulation that operated 500 times. Moreover, the contribution of structural shocks to the fluctuation of endogenous variables was also analyzed.

4.5.1. Analysis of Variance Decomposition of “Aging–Consumption–Economic Growth”

The variance decomposition is obtained via a Monte Carlo simulation of the variables $\{odep, \lnpgdp, \lnpcons\}$ using the PVAR models established by the old-age dependency ratio, the logarithm of per capita regional GDP, and the logarithm of per capita consumption expenditure. The results of the analysis of variance for the 10th and 20th projection periods are presented in Table 9.

Regarding the path considering household consumption, the results of the variance decomposition in Table 9 show that the old-age dependency ratio has a greater impact on its own shock impact, contributing 94.48% of its own variance in the 10th period and slightly decreasing to 89.16% in the 20th period.

Table 9. Results of variance decomposition for “aging-consumption-economic growth”.

Variables	Period	<i>odep</i>	<i>lnpcons</i>	<i>lnpgdp</i>
<i>odep</i>	10	0.944845	0.016859	0.038296
<i>lnpcons</i>	10	0.085842	0.696942	0.217216
<i>lnpgdp</i>	10	0.178039	0.139761	0.682201
<i>odep</i>	20	0.891658	0.029201	0.079141
<i>lnpcons</i>	20	0.083107	0.605798	0.311095
<i>lnpgdp</i>	20	0.193206	0.134569	0.672225

The old-age dependency ratio also has stronger explanatory power in terms of the per capita regional GDP growth rate, contributing 17.80% to its variance in the 10th period, thus indicating that 17.80% of the change in economic growth can be directly explained by aging. In the 20th period, it rises to 19.32%, thus indicating that the per capita regional GDP has the greatest impact on its own shock, reaching 68.22% and 67.22% in the 10th and 20th periods, respectively.

The old-age dependency ratio has less explanatory power with regard to the growth rate of per capita consumption expenditure, contributing 8.58% to its variance in the 10th period, thus indicating that 8.58% of the change in per capita consumption expenditure can be directly explained by an aging population. It decreases slightly to 8.31% in the 20th period, thus indicating that per capita consumption expenditure has the greatest impact on its own shock, reaching 69.69% and 60.58% in the 10th and 20th periods, respectively.

4.5.2. Analysis of Variance Decomposition of “Aging-Savings-Economic Growth”

The variance decomposition was obtained from the Monte Carlo simulation of the variables {*odep*, *lnpgdp*, *sav*} using the PVAR models established by the old-age dependency ratio, the logarithm of per capita regional GDP, and the national savings rate. The results of the analysis of the variance decomposition for the 10th and 20th projection periods are presented in Table 10.

Table 10. Results of the variance decomposition of “aging-savings-economic growth”.

Variables	Period	<i>odep</i>	<i>sav</i>	<i>lnpgdp</i>
<i>odep</i>	10	0.970459	0.010533	0.019008
<i>sav</i>	10	0.020463	0.847641	0.131896
<i>lnpgdp</i>	10	0.049598	0.19952	0.750882
<i>odep</i>	20	0.963421	0.016787	0.019792
<i>sav</i>	20	0.020322	0.849823	0.129855
<i>lnpgdp</i>	20	0.056371	0.236938	0.706691

Regarding national savings, the results of the variance decomposition in Table 10 show that the old-age dependency ratio *odep* has a greater impact on its own shock, contributing 97.04% of its own variance in the 10th period and slightly decreasing to 96.34% in the 20th period.

The explanatory power of the old-age dependency ratio on the per capita regional GDP growth rate reaches 4.96% of its variance in the 10th period, thus indicating that 4.96% of the economic growth change can be directly explained by an aging population. It rises to 5.64% in the 20th period, thus indicating that the per capita regional GDP has the greatest impact on its own shock, reaching 75.09% and 70.67% in the 10th and 20th periods, respectively.

The explanatory power of the old-age dependency ratio on the national savings rate contributes 2.05% to its variance in the 10th period, thus indicating that 2.05% of the change in national savings can be explained by an aging population, whereas the change is maintained at 2.03% in the 20th period. National savings have the greatest impact on their own shock, reaching 84.76% and 84.98% in the 10th and 20th periods, respectively.

5. Conclusions and Discussion

5.1. Conclusions

Using the panel data of 31 provinces (autonomous regions and municipalities directly under the Central Government) from 2000 to 2020 and the panel vector autoregressive model, this study dynamically analyzed the short-term and long-term effects of China's aging population on China's economic development, using household consumption and national savings as indicators. The empirical findings demonstrate:

- (1) Whether contemplating the path of per capita consumption expenditure or the path of the national savings rate, an aging population has a direct negative effect on economic growth. The negative effect is enduring and consistent, and it does not diminish over time. This conclusion is consistent with the conclusions of Lee and Shin [30], which stated that in countries with a high degree of aging, the majority of which are developed countries, an aging population hinders economic growth. Moreover, the impact of an aging population on economic growth is non-linear, and only when an aging population reaches a certain level will it hinder economic growth. Furthermore, as a population becomes increasingly aged, the negative effects of an aging population will become more severe. This paper demonstrates that the aging population of China is currently having a negative effect on economic development.
- (2) Regarding the indirect influence path of an aging population → consumption level → economic growth, an aging population is not conducive to an increase in consumption level, and thus, it has an impact on economic growth. According to Mao et al. [31], the increase in the elderly dependency ratio in China is a significant factor in the decline in consumption, and there is significant regional heterogeneity, with urban residents' consumption expenditure being significantly more affected by an aging population than in rural areas. Moreover, the consumption of residents in the east, central, and western regions has gradually decreased due to aging. The level of consumption demand suppression is proportional to the cost of caring for the elderly.
- (3) Regarding the indirect influence path of an aging population → national savings → economic growth, the minor positive effect of an aging population on national savings is insufficient to offset the direct negative effect of an aging population on economic growth. In fact, China's savings rate has increased substantially since 2000 [32], when it became an aging society. Scholars are generally in agreement that two factors are responsible for China's sustained upward trend with regard to savings rate. First, there is a positive correlation between variations in life expectancy and savings rates. Zhang and Wang [33] utilized panel data from 2005 to 2013 from prefecture-level cities in China, and they found that a one-year increase in life expectancy enhances the household savings rate of urban residents by 3.7%. Second, the decline in fertility and diminished family pension protections may result in a rise in precautionary savings. According to the findings of Mrohorolu and Zhao [33], China's savings rate increased from 20% to 35% between 1980 and 2010, with 10% of that increase attributed to the one-child policy and the contribution of precautionary savings fostered by pension risk. Li and Luo [34] concur that, for China, the prevention motivation caused by aging is greater than the negative impact of the life cycle on the savings rate, and the net effect of aging on household savings rate is positive.
- (4) Both direct and indirect effect analyses indicate that an aging population has a negative impact on economic growth. It is inevitable that China's aging population will continue to grow in the future, and thus, it will exert a greater drag on China's economic growth and impact the sustainable development of China's economy.

5.2. Discussion

- (1) For our research method, we employed the panel vector autoregression (PVAR) model. This does not require setting the causal relationship between variables in advance, but rather, it analyzes the influence of each variable and its lagged variables on other variables. In contrast to the conventional VAR model's requirement for a lengthy time

series, the PVAR model is distinguished by its large cross-section and short time series. Using panel data and taking into account both individual and time effects, the PVAR model is able to effectively address the issue of individual heterogeneity [28]. Strictly speaking, explanatory and control variables should be included on the right side of the econometric estimation model so that the endogeneity problem induced by omitted variables can be avoided to the greatest possible extent; in doing so, the robustness of the estimated parameters is preserved. In general, however, only delays concerning the dependent and explanatory variables are considered in PVAR model estimation, and exogenous control variables are not considered in the empirical exercises using stata or Eviews.

- (2) According to the findings of this paper's research, China's aging population is still in the early and intermediate stages. The future of China's population with regard to aging will undoubtedly have a significant impact on the country's economic growth.

Firstly, the aging population has reduced the consumption habits of residents. Due to the aging population, China's per capita consumption expenditure will continue to decline, which is not conducive to the development of residents' consumption levels. Consequently, China should enhance its pension security system. This will ensure young people can alleviate their concerns regarding sustaining the elderly, and it may increase their consumption levels. In addition, we should increase support for the "silver industry" and accurately assess the changes in market demand caused by China's geriatric population; this will increase domestic demand and fuel China's economic expansion.

Secondly, an aging population has a positive impact on national savings, and it is conducive to capital accumulation to some degree. China can use capital accumulation to increase its investment in human capital, technology, and other disciplines in order to mitigate the negative long-term effects of an aging population on economic growth. To prevent a future decline in the labor force due to an aging population, technological progress should be encouraged, with a focus on expediting the development of automation technology. To improve human capital input, on the one hand, families should be encouraged to give attention to education, enhance their children's human capital input, and promote an overall rise in individual education levels. On the other hand, as life expectancy and working hours increase, people should be encouraged to increase their investment in education and learning, as well as increase labor supply by enhancing human capital and labor quality.

Thirdly, we should accelerate the rational adjustment of family planning policies, appropriately encourage childbirth, adjust the population structure, increase the young population, and increase investment in human capital in order to provide sufficient and highly qualified labor for future economic expansion. In order to prevent an excessively aging population, scientific population policies must be improved, particularly in light of the three-year-long COVID-19 epidemic, the contracting global economy, and China's slow population growth. To address China's aging population, it is necessary to conduct extensive research on population policy, moderately liberalize the two-child and three-child policies, strengthen China's "new infrastructure" for fertility and support facilities, and review China's immigration policy.

- (3) Despite these significant findings, this study has limitations. Future research should investigate the addition of other control variables, in addition to consumption and savings, as well as innovative variables that may have a moderating effect on an aging population. New research methods, such as the spatial econometric regression model and the threshold model, should be implemented as new research objects. This study investigates the short- and long-term effects of an aging population on economic growth from the standpoint of consumption and savings. In reality, however, there is not a simple linear relationship between an aging population and economic growth [30]. An aging population can also influence economic growth in other ways, such as by affecting the supply of the labor force, causing a decline in labor productivity, preventing industrial upgrades, and increasing the pension burden;

these issues can stifle investment and thereby impact economic growth [9,35,36]. Innovation, as a significant moderating variable, can effectively moderate the effects of the abovementioned issues on economic growth. By increasing the degree of automation, innovation can effectively mitigate the effects of aging on economic growth [16]. Due to the model's limitations, the moderating effect of innovation on an aging population cannot be taken into account in its entirety during the variable selection procedure in this study. In future studies, we will investigate the use of innovation as a moderating variable of an aging population and assess its impact on economic growth in order to evaluate the significance of its moderating effect; this will provide empirical evidence concerning how to mitigate an aging population.

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