Explore the Aging of the Population and its Impact on Technological Innovation

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Abstract. The results of the seventh national population census show that the aging of the population in China has significantly accelerated, leading to a decrease in the proportion of working-age population, and thus affecting China's scientific and technological innovation. With the continuous and complex changes in the current world situation, the study of the impact of population aging on technological innovation has theoretical and practical significance. Based on this, this article selects the time series data of the proportion of people aged 65 and above in China from 1990 to 2021, uses ARIMA model to predict the development trend of population aging in the next five years. Then, panel data from 31 provinces in China from 2006 to 2019 were selected, and a two-way fixed effects model was constructed to analyze the impact of population aging on technological innovation in China. The results show that the development of population aging in China shows a trend of increasing by about 0.7 percentage points per year. The relationship between population aging and technological innovation is a significant inverted U-shaped curve relationship, with a critical value of 13.46.

Keywords: Population aging, Technological innovation, Two-way fixed effects models, ARIMA model.

1 Introduction

The global trend of population aging is unstoppable. Although countries have adopted a series of measures, such as encouraging childbirth, developing the elderly industry, carrying out medical reforms, and delaying the retirement age, to temporarily slow down the pace of population aging, they cannot fundamentally solve the problem of population aging. China is currently in the stage of mild aging, and after the census, the issue of population aging has once again attracted attention. The United Nations predicts that China will enter a deeply aging society in 2025. Due to the decrease in the birth rate and the extension of life expectancy, the degree of population aging in China has further deepened, resulting in a weakening of the "population dividend" and a decline in labor productivity. Factors such as human capital, labor productivity, and research resources will affect technological innovation, and population aging is the key

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factor determining these factors, which will inevitably affect China's technological innovation.

China's economic development, which was driven by traditional factor-driven growth mode, shifted from high-speed growth to medium-high speed growth since 2012. The slowdown in economic growth reflects the insufficient driving force of traditional factor-driven growth mode. In the future, economic growth will increasingly rely on the driving role of technological innovation. As an endogenous driving force for economic development, technological innovation is a key to promoting social development and a powerful means of solving various challenges facing China's current social development, which can promote a transformation in development mode.

In order to study the impact of population aging on technological innovation and draw specific feasible conclusions, this article first uses the method of literature research to obtain relevant materials by searching for papers and journal articles. Then, using the ARIMA model to analyze the past aging situation and predict the proportion of the elderly aged 65 and above in the next five years in China. Then, using the model testing method, starting from the proxy indicators of technological innovation and population aging, using R&D investment intensity as an indicator of measuring the level of technological innovation, and the proportion of the population aged 65 and above to the total population as an indicator of measuring the degree of population aging in China, the article employs the time-individual two-way fixed effect model for empirical analysis and testing.

2 Journals reviewed

By analyzing and summarizing existing research literature, it can be found that China has the largest elderly population in the world [1]. By the end of 2019, the elderly population aged 60 and above in China reached 254 million, accounting for 18.1% of the total population [2]. Zhang and Song predicted in their report that by 2050, the population aged 60 and above in China will reach 483 million, accounting for about 34.1% of the total population [3]. Large population base and fast development are typical characteristics of population aging in China.

In terms of the impact of population aging on technological innovation, although there is no unified conclusion in current academic research, existing literature has put forward three main views on the impact of population aging on technological innovation.

The first view is the promotion theory. Habakkuk (1962) believed that the reduction of labor force will promote innovation [4]. Lee and Mason (2010), Bloom (2010) found that aging labor force structure has a positive impact on innovation [5-6]. The decrease in labor supply and aging of the labor force brought by population aging will stimulate the society to adopt technological substitution of labor, thereby driving the development of technological innovation. Scarth (2002) believed that when the labor force decreases, the society will turn to industries with high labor skills, thereby promoting labor productivity [7]. Rapid aging and irreversible reality of aging labor force, the decrease of labor force age can foster the development of emerging elderly care industry and promote the development of advanced technologies such as artificial intelligence. The labor substitution brought by population aging is conducive to improving labor productivity. Skirbekk (2004) believed that older employees have a positive impact on innovation capacity [8].

The second view is the inhibition theory. Chun Y J (2013) found that population aging reduces effective labor force and inhibits technological progress [9]. Czaja et al. (2007) believed that population aging inhibits personal technological innovation by reducing physical and cognitive abilities [10]. Population aging will increase the government's financial burden of pensions, affecting the effectiveness of fiscal and monetary policies. Bloom et al. (2003) believed that the increase in life expectancy will improve total factor productivity [11]. Gehringe and Prettner (2019) also agree with this view, and verified the positive correlation between the increase in life expectancy and total factor productivity by using data from 22 OECD countries from 1960 to 2011 [12].

The third view is the inverted U-shaped theory. In addition to the above two theories, some scholars believe that the relationship between the two is not a simple linear relationship, but more complex nonlinear relationship. Rossman (1935) pointed out through the study of inventors that the impact of age on technological innovation changes dynamically for micro individuals [13]. Feyrer (2008) found a significant inverted U-shaped relationship between labor force age and total factor productivity [14]. However, some scholars believe that Feyrer's (2008) article is too sensitive to the model setting, and its research results are not credible [15]. Therefore, further research is needed on the relationship between population aging and technological innovation.

3 Prediction of population aging

Obtaining the age structure data of the Chinese population from the "China Statistical Yearbook (1990-2021)," we processed and obtained a time-series data of the proportion of the population aged 65 and over to the total population for 32 years from 1999 to 2021.

3.1 Time series preprocessing

First, check the stability of the original time series, and draw the time sequence diagram of the time series of the proportion of the population over 65 years old, as shown in Figure 1.

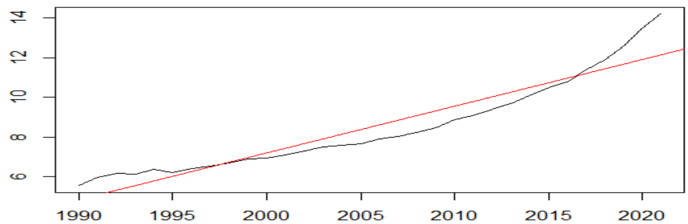

Fig. 1. Time series plot.

From Figure 1, it can be seen that the data has a significant increasing trend. During the period of 1995-2000, the time series growth trend developed more slowly. From 2015 to 2021, the time series growth was more pronounced, possibly due to the combined effect of the family planning policy leading to a decrease in birth rate and the improvement of medical level resulting in an extension of life expectancy. The proportion of elderly population increased more than twice in the 32 years compared to 1990, and the problem of population aging is more prominent with an accelerated pace. It is preliminarily judged that this sequence is a non-stationary time series. To transform the non-stationary time series into a stationary time series, the original sequence can be differenced. The ndiffs() function in the forecast package can help determine how many times the data needs to be differenced. The result of ndiffs() is 2, so we choose to take the second difference of the original data of the proportion of population aged 65 and over to construct a stationary time series. The time series plot after second differencing is shown in Figure 2.

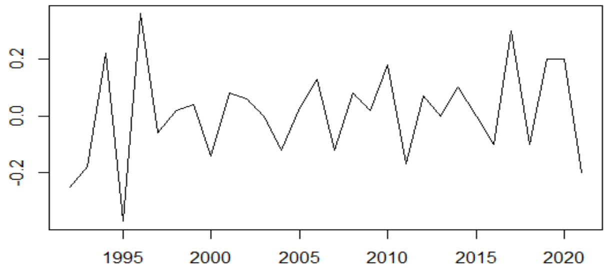

Fig. 2. Time series plot after differencing.

From the time series plot in Figure 2, it can be seen that the second differenced sequence fluctuates around zero and does not change with time, indicating that the growth trend of the time series has been eliminated after second differencing. However, visual inspection of the plot may lead to some errors in the results, so a unit root test is also performed on the differenced time series. The p-value of the unit root test is 0.01, which rejects the null hypothesis at a significance level of 0.05, indicating that there is no unit root in the time series after two differencing, and the second differenced time series can be considered stationary. The time series plot and unit root test results together suggest that the original sequence has been sufficiently processed, and an ARIMA model can now be constructed for the time series.

3.2 Model order determination and model diagnosis

Generally, existing literature combines the ACF and PACF plots of the differenced series to determine the values of p and q in the ARIMA model. Therefore, we use R to plot the ACF and PACF plots of the second differenced time series, as shown in Figure 3. From Figure 3, we can see that the ACF plot shows that the autocorrelation coefficient is truncated at the first order, and thus, we select an ARIMA (0,2,1) model.

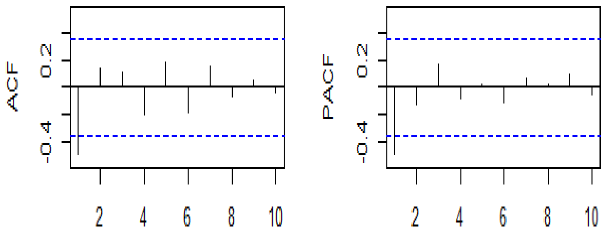

Fig. 3. Autocorrelation plot and Partial autocorrelation plot after differencing.

After building the ARIMA model, we need to test it to ensure that it is suitable for future predictions. The ACF and PACF plots of the ARIMA model are shown in Figure 4.

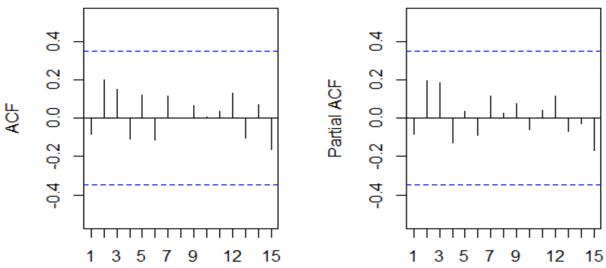

Fig. 4. Autocorrelation plot and Partial autocorrelation plot for ARIMA model.

To perform a hypothesis test on the residuals of the ARIMA (0,2,1) model, it is necessary to test whether the residuals are normally distributed and whether they exhibit randomness. In this study, a Q-Q plot was used to test for normality, and a white noise test was used to test for randomness. The Q-Q plot results are shown in Figure 5, which indicates that, ignoring extreme cases on both sides, most of the points are distributed around the line, indicating that the residuals conform to normality. With a confidence interval set at 99%, the p-value for the white noise test was 0.6265, which is far greater than 0.01, and therefore not statistically significant. The null hypothesis cannot be rejected, indicating that the residuals are random and do not affect each other.

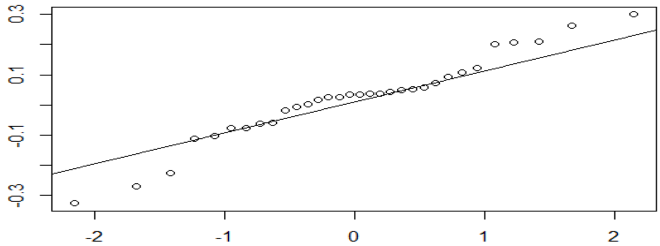

Fig. 5. Q-Q plot.

3.3 Result prediction

Through the construction of ARIMA model and the hypothesis test of the model, we can get the following models for predicting population aging:

$$\Delta X_t = Z_t - 0.4716Z_{t-1} \quad (1)$$

The development trend of population aging in China in the next five years was predicted using the ARIMA (0,2,1) model, and the results are shown in Table 1. As can be seen from Table 1, the trend of national population aging shows an almost annual increase of 0.7 percentage points, with approximately 14.93% in 2022, 15.66% in 2023, 16.38% in 2024, 17.11% in 2025, and 17.84% in 2026. Hi 95 and Lo 95 represent the maximum and minimum values in the 95% confidence interval, respectively. It appears that China's population aging is developing more severely, according to the international standard for countries with deep aging, which is when the proportion of the elderly population aged 65 and above reaches 14% of the total population. Combining the ARIMA model's prediction results on China's population aging, the country may have entered a state of deep aging before 2025.

Table 1. Prediction Results Table.

Year	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95
2022	14.9277	14.7406	15.1148	14.6415	15.2138
2023	15.6553	15.3136	15.9971	15.1327	16.1780
2024	16.3830	15.8683	16.8976	15.5958	17.1701
2025	17.1106	16.4043	17.8169	16.0304	18.1908
2026	17.8383	16.9227	18.7539	16.4380	19.2385

4 Analysis of empirical results

4.1 Model design

Based on the analysis and compilation of existing literature, it can be seen that the impact of aging population on technological innovation will be influenced by factors such as the level of transportation infrastructure, birth rate, and economic development level. Considering the issue of endogeneity, which means that there may be a correlation between the independent variables and random disturbance terms, leading to biased estimates in regression, this study chooses to establish a two-way fixed effect model as follows:

$$R\&D_{it} = \alpha_0 + \alpha_1 AGE_{it} + \alpha_2 AGE_{it}^2 + \alpha_3 X_{it} + \alpha_4 I_t + \alpha_5 T_t + \varepsilon_{it} \quad (2)$$

In this equation, α_0 is the constant term, i represents the ith province in China, t represents the year. R&Dit represents the level of technological innovation in province i in year t, for example, R&D1,2014 represents the level of technological innovation in Beijing in 2014. AGEit represents the aging population index in province i in year t, AGEit2 represents the quadratic term of the aging population index in province i in year t.

Xit represents a collection of other control variable information that may affect technological innovation, in addition to the variable AGEit. This includes information on the level of transportation infrastructure (Infra), the number of patent applications granted per million people (Patent), the birth rate (Natality), and the level of economic development (GDP). Tt represents time fixed effects, It represents province fixed effects, and εit represents the random disturbance term. The quadratic term AGEit2 is included in the model to test whether there is a non-linear relationship between technological innovation and population aging.

4.2 Variable definition and descriptive statistics

Selected panel data at the provincial level from 2006 to 2019 were used for empirical analysis. To ensure consistency in data sources and reliability and timeliness of data, all data used in this paper were obtained from official statistical results. R&D intensity and per capita patent applications by region were obtained from the "China Science and Technology Statistics Yearbook (2006-2019)", while population structure by region and the number of year-end residents by region were obtained from the "China Population and Employment Statistics Yearbook (2006-2019)". The remaining data were obtained from the "China Statistical Yearbook (2006-2019)". After obtaining the official data, panel data at the provincial level were processed using Excel based on actual needs. This paper only studies data from 31 provinces and does not involve the three regions of Hong Kong, Macao, and Taiwan.

Table 2 shows the definition and descriptive statistics of the indicators used in the study.

Table 2. Variable definition and descriptive statistics.

Variable	Variable	N	mean	sd	min	max
R&D	The ratio of research and development expenditure to gross domestic product	434	1.503	1.095	0.170	6.310
AGE（%）	The proportion of the population over 65 years old	434	9.744	2.198	4.820	16.26
Infra	The sum of road mileage, inland waterway mileage, and railway operating mileage divided by the land area	434	0.911	0.554	0.0400	2.540

Patent	Number of Patents per 10,000 people	434	13.81	18.30	0.310	105.0
Natality		434	5.996	0.751	4.210	7.570
Gdp		434	41,846	26,471	6,103	164,563

4.3 Preliminary regression results

Table 3 reports the estimation results of Equation (1), with five columns in total. In order to preliminarily verify the impact of population aging on technological innovation, only the population aging indicators AGE and AGE^2 are introduced in the column (1). In the column (2), the level of transportation infrastructure (Infra) is also introduced. In the column (3), the level of transportation infrastructure (Infra) and the number of patent applications and authorizations per 10,000 people (Patent) are introduced. In the column (4), the level of transportation infrastructure (Infra), the number of patent applications and authorizations per 10,000 people (Patent), and the birth rate (Natality) are introduced.

The column (5) is the econometric analysis after introducing all control variables, and it can be seen that the coefficient of AGE2 is -0.024, significant at the 0.01 level, and the coefficient of transportation infrastructure level (Infra) is positive and significant at the 0.05 level, while the coefficients of other variables are all significant at the 0.01 level.

Table 3. Regression results of two-way fixed effect model.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
AGE(%)	0.556*** (9.58)	0.265*** (6.28)	0.392*** (8.27)	0.555*** (9.77)	0.646*** (11.26)
AGE2	-0.016*** (-5.17)	-0.010*** (-5.39)	-0.016*** (-6.25)	-0.019*** (-6.45)	-0.024*** (-7.42)
Infra		1.034*** (20.84)	0.261*** (11.86)	0.306*** (12.95)	0.086** (2.37)
Patent			0.043*** (12.93)	0.035*** (14.96)	0.016*** (4.38)
Natality				-0.389*** (-8.82)	-0.250*** (-11.65)
Gdp					0.000*** (4.57)
Intercept	-2.361*** (-8.54)	-1.036*** (-4.54)	-1.577*** (-6.32)	-0.416 (-1.54)	-2.079*** (-5.53)
N	434	434	434	434	434

Province fixed effect	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	yes	yes	yes
R2	0.200	0.374	0.674	0.714	0.743
Critical value (%)	17.38	13.25	12.25	14.61	13.46

The quadratic coefficients of the population aging index in the regression results of the 5 columns are all negative and have passed the significance test. Once again, the regression results confirm the inverted U-shaped relationship between population aging and technological innovation. This relationship shows that before reaching the critical value, population aging promotes technological innovation. However, after reaching the critical value, population aging has a negative impact on technological innovation. In the early stages of an aging population, the increasing proportion of young elderly people reduces the consumption burden caused by too many minors in the region, which leads to more funds being used for accumulation and increases the proportion of investment in reproduction. This is conducive to industrial technology transformation and promotes technological innovation. After a period of time, when the critical value of 13.46% is reached, the decrease in the proportion of the labor force leads to a decrease in labor productivity, an increase in elderly care expenses, and a reduction in the investment in technological innovation. Population aging then begins to inhibit technological innovation. Currently, there are 9 provinces that have exceeded the critical value, including Shanghai, Liaoning, Shandong, Sichuan, Chongqing, Jiangsu, Zhejiang, Anhui, and Heilongjiang. However, according to the "China Regional Science and Technology Innovation Capability Report 2021," some provinces such as Shanghai do not conform to the research results on technological innovation capabilities, which is worth other provinces learning from. In the irreversible situation of population aging, new breakthroughs should be sought for technological innovation.

4.4 Robustness test

There are many methods to test the robustness of existing literature models, such as variable substitution, subsample regression, setting dummy variables, adding variables, and using lagged one-period GMM. In this study, we chose the variable substitution method to test the robustness of the two-way fixed effects model while keeping the regression model form unchanged and controlling other control variables. In the previous section, the proportion of the population aged 65 and above to the total population was chosen to measure the level of aging, which is now replaced with the elderly dependency ratio. The elderly dependency ratio is defined as the ratio of the population aged 65 and above to the population of working age (15-64 years old).

$$Oadr = \frac{the\ population\ over\ 65\ years\ old}{the\ population\ of\ working\ age} * 100\% \tag{3}$$

Table 4. Regression results of robustness test.

	(1)	(2)	(3)	(4)	(5)
Oadr(%)	0.357*** (6.70)	0.090* (1.93)	0.164*** (3.86)	0.293*** (6.03)	0.358*** (7.49)
$Oadr^2$	-0.008*** (-4.65)	-0.004** (-2.87)	-0.005*** (-3.33)	-0.007*** (-4.15)	-0.010*** (-5.14)
Infra		1.236*** (29.30)	0.370*** (13.29)	0.378*** (13.25)	0.120*** (3.08)
Patent			0.043*** (13.29)	0.038*** (15.59)	0.017*** (4.05)
Natality				-0.351*** (-7.35)	-0.228*** (-11.94)
Gdp					0.000*** (4.41)
Intercept	-1.688*** (-4.31)	-0.092 (-0.26)	-0.650* (-2.14)	-0.223 (0.72)	-1.425*** (-3.56)
N	434	434	434	434	434
Province fixed effect	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	yes	yes	yes
R2	0.102	0.366	0.660	0.688	0.722
Critical value (%)	22.31	11.25	16.40	20.93	17.90

The regression results of robustness test are shown in Table 4. From Table 4, it can be seen that except for the coefficient of Oadr2 in the second column which has become significant at the 0.05 level, the coefficients of Oadr2 in the other regression results are still significant at the 0.01 level. It can also be seen that the coefficients of the first and second order terms of the population aging index are slightly smaller than those in the previous model. The critical value of the model with all control variables added is 17.9%, which is larger than the 13.46% of the previous model. This is because the denominator of AGE is the total population, while the denominator of Odar is the total number of labor force population aged 14-64, so it is reasonable for the critical value to be larger.

5 Conclusions and policy implications

5.1 Conclusion

According to the seventh national population census, China is approaching moderate aging, with 12 provinces having a proportion of 65 and above elderly population to the total population reaching 14%, indicating a severe aging population situation. China's aging population mainly exhibits four characteristics: firstly, the aging process has significantly accelerated. Compared with the decade from 1990 to 2000, the growth rate in the decade from 2010 to 2020 has been larger, and the growth level in the fastest decade can match the growth level of the previous 30 years. Secondly, there is a large number of elderly people, with a population of 190 million aged 65 and above. Thirdly, there is a significant difference in aging between eastern and western regions, with the aging degree in the western region far lower than that in the eastern coastal area. Most cities in the eastern coastal area have a proportion of 65 and above elderly population exceeding 10%, while many in the western region are below 10%, and the growth rate in the western region is slower than that in the eastern region. Fourthly, the quality of the elderly population continues to improve, with a higher proportion of educated people. Aging population will be a basic national condition in China for a long time to come. It is necessary to accelerate the transformation of thinking, better utilize the resources of low-age elderly people, and help China achieve its second centenary goal.

In the next five years, China's aging population is expected to increase by approximately 0.7 percentage points each year, presenting a relatively severe form of population aging, and the proportion of people aged 65 and above will reach 14.9% in 2022, surpassing the critical value of population aging's impact on technological innovation. Predicting the development trend of China's aging population in the next five years and combining it with its impact mechanism on technological innovation can provide reference for promoting technological innovation and provide a basis for promoting the development of elderly care.

Based on the above background, this paper used stata software to conduct a quadratic regression analysis on 31 provincial panel data from 2006 to 2019, solved the endogeneity problem based on fixed individuals and time, and made the regression results more accurate. Then, the elderly population dependency ratio was used to replace the proportion of the population aged 65 and above in the two-way fixed-effect model for robustness testing. Finally, the ARIMA model was used to build a time series of 65 and above elderly population proportion from 1990 to 2021 and predict the future five-year development trend using Rstudio software. Based on the above research, the following conclusions are drawn:

The impact of population aging on technological innovation does not exhibit a simple linear structure, but rather a U-shaped structure with a critical value of 13.46. When entering an aging society, the aging index does not exceed the critical value, and population aging has a promoting effect on technological innovation. At this time, with a lower level of aging, there are relatively more younger elderly people with good physical conditions and greater creativity, and a series of measures, such as setting up universities for the elderly, delaying retirement age, and rehiring retired employees, can be used to fully utilize elderly resources and improve technological innovation. The burden of elderly care to some extent leads to a decline in fertility rate, a decrease in consumption expenditure by minors, and more funds used for industrial upgrading. Enterprises, seeking more profits, actively seek technological progress on the basis of increasing labor costs, and various reasons promote technological innovation to some extent. After a period of time, population aging exceeds the critical value, and the increasing number of elderly people, continuous decline in fertility rate, and improved medical level lead to a situation where there are relatively more elderly people. At this time, elderly care needs more investment, which squeezes the investment of technological innovation resources, and is not conducive to technological innovation. Because these elderly people are not highly interested in learning and lack learning experience, they cannot be converted into labor resources, which further affects technological innovation.

This study did not consider the problem of population mobility among provinces. Although some provinces have severe aging, the level of technological innovation is still improving. Considering that labor-aged population in western regions will flow to eastern coastal areas due to lower economic development levels, and some provinces with more developed economies can introduce more talents to assist technological innovation, this may cause errors in the analysis of the relationship between population aging and technological innovation. Also, there is a lack of discussion on whether there are differences in the influencing mechanisms and short-term versus long-term impacts.

5.2 Countermeasures and suggestions

According to empirical analysis, it can be seen that the aging process of China's population is accelerating, and population aging has become a trend in China's social development. With population aging being an irreversible situation and a basic national condition, it is necessary to actively reduce its negative impact on technological innovation through various means.

Firstly, vigorously develop the "silver economy". With policy support and market demand, the "silver economy" presents numerous opportunities, and its development can drive market and social innovation, improve the labor productivity of all members, and promote industrial upgrading. Combined with the needs of the elderly in terms of clothing, food, housing, and transportation, the development of the elderly industry should be promoted, and elderly care services should be provided. Support should be increased, especially for some small and medium-sized enterprises, with increased funding and technical support. For employees, professional training should be strengthened. Relevant laws and policies should be issued to create a favorable business environment and promote the development of the "silver economy."

Secondly, tap the potential of the younger elderly population. With a large population base in China, there are many younger elderly people. Compared with young people, these elderly people who are approaching retirement age or have just retired from their original positions have the advantages of knowledge, skills, and experience. By making good use of delaying retirement age and re-employing retired personnel, not only can the elderly fully exert their value, but also more possibilities for technological innovation can be provided to a certain extent.

Thirdly, improve the quality of education and cultivate talents for technological innovation. Since population aging has a negative impact on technological innovation, other means should be used to improve the level of technological innovation. The education level of a country has a profound impact on its ability for technological innovation. Children's hands-on abilities should be cultivated from an early age, and they should be encouraged to think and innovate more. Scientific and cultural literacy should be improved, and people needed in the field of technology should be cultivated. Especially with the significant gap between urban and rural education in China, educational resources should be reasonably tilted towards rural areas to enable residents in all regions to enjoy education equally. Ultimately, increasing the stock of human capital can promote technological innovation.

Fourthly, reasonable fertility policies should be introduced. Whether it is the two-child policy passed at the Fifth Plenary Session of the 18th CPC Central Committee in 2015, or the three-child policy passed in 2021, they are both manifestations of China's active efforts to slow down population aging. After the implementation of these policies, regional differences must also be considered, and relevant supporting policies must be introduced to truly implement the policies. For areas where policies are unreasonable, opinions should be actively collected for revision, and the desire for childbirth among suitable women should be stimulated to increase China's fertility rate, thereby slowing down the trend of population aging and promoting technological innovation.

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