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The Influence of Aging on Technological Innovation: Empirical Evidence from China

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Using panel data from 30 Chinese provinces for the period between 2003 and 2017, this paper explores the relationship between the aging and technological innovation. The global principal components analysis is used to construct the index system of technological innovation from three aspects: innovation input, innovation output and innovation diffusion. Then, the inverted U-shape relationship between population aging and technological innovation is obtained from the dynamic perspective by using two-step system generalized method of moments (SYS-GMM). The influence of population aging on technological innovation is firstly promoted and then suppressed. In addition, the degree of opening up, the level of economic development, the construction of network infrastructure and human capital all have positive impact on technological innovation.

Keywords: Aging, Inverted U-shape, System GMM, Technological innovation

Introduction

Technological innovation is the driving force of social development. It promotes economic growth in a variety of ways, such as increasing factor productivity, adjusting industrial structure.[1,2] In addition, as countries pay more and more attention to environmental problems, technological innovation has also made positive contributions to environmental protection in some ways, such as developing clean energy and improving waste treatment. Advances in medical technology make people live longer. Coupled with the change in the concept of fertility, many countries are facing the problem of aging. Technological innovation is a complex work. People play a leading role in technological innovation activities. Therefore, the aging population will inevitably have an impact on technological innovation. The main influence paths can be summarized as the following. First of all, people's innovation ability changes with the growth of age due to the differences in physical function, cognitive ability and work experience.[3,4] Secondly, the increasing proportion of the elderly population will also have an impact on the government's fiscal expenditure.[5] Pensions crowding out R&D expenditures may have a negative impact on technological innovation. Finally, with the deepening of aging, rising labor costs will force companies to replace labor with technology.[6] This will have a positive impact on technological innovation. Therefore, the impact of population aging on technological innovation is multifaceted. The specific impact needs empirical test. This paper uses the provincial panel data of China to test the impact of population aging on technological innovation.

Empirical Model and Estimation Method

Empirical Model

Innovation activities have a strong continuity. The current innovation activities are affected by the previous innovation activities. Obviously, regions with more innovation resources and achievements are more inclined to continue innovating. In order to study the relationship between population aging and innovation ability from a dynamic perspective, the first-order lag term of innovation ability is introduced into the model. In addition, considering the nonlinear influence of population aging on technological innovation, the quadratic term of aging is introduced to establish the regression model as shown in Eq. (1):

$$Inn_{\mathrm{it}} = \mathrm{C} + \beta_0 Inn_{\mathrm{i,t-1}} + \beta_1 O_{\mathrm{i,t}}^2 + \beta_2 O_{\mathrm{i,t}} + \sum \alpha_{\mathrm{m}} control_{\mathrm{i,t}} + \mu_{\mathrm{i}} + \varepsilon_{\mathrm{i,t}} \quad \ldots (1)$$

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where subscripts i and t represent province and time period respectively, *Inn* denotes technological innovation, *O* denotes population ageing, *control* denotes other control variables that affect technological innovation, μ is provincial effect, ε is random error.

Estimation Method

This paper introduces the first-order lag of technological innovation ability to consider the relationship between aging and technological innovation from a dynamic perspective. But it also brings endogenous problems to the model. In addition, not only the aging has an impact on the technological innovation ability of the society, but also the technological progress of the society will extend people's life and deepen the aging of the population. This two-way causal relationship will also produce endogenous problems. Arellano and Bond proposed the first-difference generalized method of moments (DIF-GMM) method in 1991 to solve the endogenous problems.[7] However, the DIF-GMM is prone to produce weak instruments, and will eliminate the effects of parameters that do not change with time. In order to overcome these problems, Blundell and Bond proposed the system generalized method of moments (SYS-GMM) in 1998.[8] SYS-GMM is divided into one-step and two-step methods. The two-step method is more effective after two step covariance matrix for sample correction.[9] Therefore, this paper uses the two-step method SYS-GMM to estimate the model.

Variable Selection and Data Sources

Technological Innovation Capability

Technological innovation ability is the core explained variable. A single index could not accurately measure the improvement of the technological innovation ability. This article measures the innovation ability of a region from three dimensions: technological innovation input, technological innovation output and innovation achievement diffusion. Innovation input includes intramural expenditure on R&D and full-time equivalent of R&D personnel. Innovation output includes the number of patent grants and the number of SCI papers published that year. Diffusion of innovation is measured by the turnover of the technology market. The specific measurement system is shown in Table 1.

Table 1 — Evaluation system of technology innovation ability

Primary index	Secondary index	Unit
Innovation input	Intramural Expenditure on R&D (V_1)	Billion yuan
	Full-time Equivalent of R&D Personnel (V_2)	man-year
Innovation output	Number of patents granted (V_3)	Piece
	Number of SCI publications (V_4)	Piece
Diffusion of innovation	Technical market turnover (V_5)	Ten thousand yuan

Aging Degree

The degree of population aging is measured by the ratio of elderly population support (OAD) in the sample period.[10] The calculation method is: ratio of elderly population over 65 to working-age population. In addition, this article uses the population aging coefficient (COA) to conduct the robustness test. The calculation method is: ratio of the elderly population over 65 to the total population.

Controlled Variables

Other factors affecting technological innovation used in this paper include: (1) Degree of openness (Openness). The more open a region is, the more foreign innovative talents and advanced technologies can be absorbed, which will have a positive impact on the technological innovation and productivity.[11] However, some scholars believe that over-reliance on foreign technology is not conducive to domestic independent innovation. This article measures the degree of openness with the ratio of the total import and export of goods to GDP. (2) Economic development level (GDP). The level of regional economic development is an important factor affecting technological innovation. The more developed the economy, the more it can invest in science and technology. In this paper, the real GDP per capita is used to represent the economic development level of a region. (3) Information infrastructure (Inf). Information technology can promote technological innovation by accelerating knowledge sharing, improving labor efficiency and shortening product development cycles. Information technology is an important factor affecting whether new ideas can be transformed into innovation output. Therefore, the level of innovation ability of a region also be affected by the level of information infrastructure construction. In this paper, the optical fiber mileage per square kilometer is used to represent the level of information infrastructure construction. (4) Human capital (Hum). After the formal training, the cognitive ability of the workforce is improved. As a result, areas with higher levels of education in the workforce tend to have higher innovation vitality. In this paper, the ratio of the population with college degree to the population over 6 years old is used to represent the level of human capital.

China entered the aging society in 2000. Based on the data availability, this paper uses panel data of 30 provinces and autonomous regions of China (excluding Hong Kong, Macao, Taiwan and Tibet) from 2003 to 2017 for empirical analysis. The data utilized in this study were compiled from the China Statistical Yearbook, China Science and Technology Statistical Yearbook and Statistical Yearbooks of Provinces. The partial missing values are compensated by interpolation. Excluding the impact of price factors on real GDP per capita, with 2003 as the base period, the annual nominal GDP of each region will be deflated.

Empirical Results and Discussion

The Synthesis of Technology Innovation Index

In order to reduce the dimensions of basic indexes of technological innovation, this paper uses SPSS23 software to conduct time series global principal component analysis (GPCA). However, the dimensions and orders of magnitude of each basic index are different. If the original index is directly used for analysis, the role of the larger order of magnitude index will be highlighted and the evaluation results cannot be reasonably reflected. Therefore, before the time series global principal component analysis, the data is processed by the standard deviation. When using GPCA for dimension reduction, it was observed that the score of the KMO sampling suitability measure was 0.766, which was greater than 0.7. And the significance level of the Bartlett sphere test was 0.000, strongly rejecting the original hypothesis that the correlation coefficient matrix of the original variable is the identity matrix, indicating that principal component analysis can be conducted. The Eigen value and the cumulative variance contribution rate are calculated, as shown in Table 2. The cumulative contribution rate of the two principal components extracted is 88.723%, which is greater than 85%, indicating that the principal component basically covers the information of all indicators. The component score coefficient matrix is shown in Table 3. The linear combination expression of the two principal components is:

$$F_1 = 0.267V_1 + 0.258V_2 + 0.248V_3 + 0.210V_4 + 0.176V_5 \quad \text{...(2)}$$

$$F_2 = -0.103V_1 - 0.358V_2 - 0.463V_3 + 0.384V_4 + 0.874V_5 \quad \text{... (3)}$$

According to the contribution rate of the main components in Table 2 and the score coefficient of the components in Table 3, the index of technological innovation can be calculated. The calculation method is as follows. The technological innovation score of each province is calculated according to Eq. (4).

$$Inn = 0.2010V_1 + 0.1428V_2 + 0.1212V_3 + 0.2410V_4 + 0.3005V_5 \quad \text{... (4)}$$

The Influence of Aging on Technological Innovation

Next, we used Stata14 to regress the model, the estimation results are shown in Table 4. In Table 4, the model (1) only considers the first-order lag item of technological innovation capability, the linear and quadratic terms of aging. Then gradually adds a series of control variables. Get the models (2), (3), (4), (5). According to the test results of AR (1) and AR (2), there is first-order autocorrelation but no second-order autocorrelation in the disturbance term. The null hypothesis that the disturbance term has no autocorrelation can be accepted. The estimation results of Hansen test show that the original hypothesis of the validity of instrument variables cannot be rejected, which means that the instrument variables of the models in this paper do not have excessive recognition problems. The result of SYS-GMM is valid.

In Table 4, the regression coefficients of the explanatory variables of model (1) are significant at the 1% significance level. The aging of the population structure has a significant impact on technological innovation, presenting an inverted U-shape characteristic. In the other four models, the coefficient and significance level of OAD and OAD2 remained

Table 2 — Total variance explained

Component	Initial Eigen values			Extraction sums of squared loadings		
	total	% of variance	cumulative %	total	% of variance	cumulative %
1	3.645	72.902	72.902	3.645	72.902	72.902
2	0.791	15.822	88.723	0.791	15.822	88.723
3	0.452	9.032	97.755	—	—	—
4	0.080	1.602	99.358	—	—	—
5	0.032	0.642	100.000	—	—	—

Table 3 — Component score coefficient matrix

Component	V1	V2	V3	V4	V5
1	0.267	0.258	0.248	0.210	0.176
2	−0.103	−0.358	−0.463	0.384	0.874

stable after adding a series of control variables. In the early stage of China's aging, the moderate aging of labor force contributes to the "learning by doing". With the increase of labor cost, enterprises have increased their investment in R&D. The aging population has a positive effect on technological innovation. But the deepening aging not only reduces the ability of the entire society to accept new knowledge and skills, but also reduces the investment in innovation. The pension occupies the state's investment in innovation. The effect of aging on technological innovation has turned into inhibition.

Robustness Test

In order to make the results robust, this paper uses the aging population coefficient to replace the dependency ratio of aging for robustness test. The test results are shown in Table 5. In Table 5, the model (6) only considers the first-order lag item of technological innovation capability, the linear and quadratic terms of aging. Then gradually adds a series of control variables. Get the models (7), (8), (9), (10). The results are consistent with the basic regression model, supporting the effect of aging on the technological innovation is an inverted "U" relationship that first

Table 4 — The GMM regression result of the OAD on technological innovation

	(1)	(2)	(3)	(4)	(5)
L.D	1.1368*** (0.0126)	1.1119*** (0.0181)	1.0737*** (0.0157)	1.0632*** (0.0265)	1.0494*** (0.0323)
OAD	0.0265*** (0.0079)	0.0211*** (0.0073)	0.0184*** (0.0045)	0.0233*** (0.0062)	0.0190*** (0.0058)
OAD^2	−0.00109*** (0.0003)	−0.00084*** (0.0003)	−0.00072*** (0.0002)	−0.00091*** (0.0002)	−0.00073*** (0.0002)
Openness		0.0173 *** (0.0061)	0.0165*** (0.0058)	0.0120* (0.0072)	0.0258** (0.0103)
GDP			0.0104 *** (0 .0035)	0.0117*** (0.0042)	0.0101** (0.0048)
Inf				0.0390 (0.0559)	0.0178 (0.0393)
Hum					0.0494 (0.0598)
constant	−0.1522*** (0.0491)	−0.1278*** (0.0457)	−0.2127*** (0.0480) (0.0480)	−0.2612*** (0.0552)	−0.2252*** (0.0593)
AR (1)	−2.77 [0.006]	−2.88 [0.004]	−2.92 [0.004]	−2.83 [0.005]	−2.89 [0.004]
AR (2)	1.59 [0.111]	1.63 [0.103]	1.62 [0.105]	1.63 [0.103]	1.63 [0.104]
Hansen	26.12 [0.247]	24.35 [0.183]	28.69 [0.428]	25.36 [0.188]	26.82 [0.419]
Inflection point	12.16	12.56	12.78	12.80	13.01

Note: ***, **, and * represent significant levels at 0.01, 0.05, and 0.1, respectively; Standard deviation in parentheses, P value in brackets

Table 5 — The GMM regression result of the COA on technological innovation

	(6)	(7)	(8)	(9)	(10)
L.D	1.1353*** (0.0193)	1.1226*** (0.0209)	1.0712*** (0.0154)	1.0607*** (0.0185)	1.0543*** (0.01857)
COA	0.0313*** (0.0107)	0.0297*** (0.0114)	0.0214*** (0.0049)	0.0143** (0.0070)	0.0143** (0.0066)
COA^2	−0.00185*** (0.0006)	−0.00171*** (0.0006)	−0.0012*** (0.0003)	−0.00078*** (0.0004)	−0.00076** (0.0004)
Openness		0.01318** (0.0064)	0.0185*** (0.0058)	0.0267*** (0.0267)	0.0301*** (0.0099)
GDP			0.0093*** (0.0035)	0.0109*** (0.0038)	0.0109** (0.0044)

(*Contd.*)

Table 5 — The GMM regression result of the COA on technological innovation (*Contd.*)

	(6)	(7)	(8)	(9)	(10)
Inf				0.0127 (0.0321)	0.0126 (0.0346)
Hum					0.0028 (0.0566)
constant	−0.1231** (0.0491)	−0.1242** (0.0501)	−0.1823*** (0.0448)	−0.1720*** (0.0487)	−0.1744*** (0.0554)
AR (1)	−2.49 [0.013]	−2.44 [0.015]	−2.84 [0.005]	−2.99 [0.003]	−2.99 [0.003]
AR (2)	1.56 [0.118]	1.58 [0.114]	1.63 [0.102]	1.63 [0.102]	1.64 [0.100]
Hansen	26.46 [0.189]	23.46 [0.218]	26.54 [0.326]	26.49 [0.492]	25.97 [0.465]
Inflection point	8.50	8.68	8.96	9.17	9.41

Note: ***, **, and * represent significant levels at 0.01, 0.05, and 0.1, respectively. Standard deviation in parentheses, P value in brackets.

promotes and then hinders. Moreover, the impact of the level of opening up, the level of economic development, information infrastructure construction and human capital on technological innovation is positive. They all can increase the critical value, which shows that the results are robust.

Conclusions

Using panel data from 30 Chinese provinces for the period between 2003 and 2017, this paper explores the relationship between the aging and technological innovation. The influence of population aging on technological innovation is firstly promoted and then suppressed. However, the degree of opening up, the level of economic development, the construction of network infrastructure and human capital can all promote technological innovation. In addition, they can also delay the turning point of negative impact of population aging on technological innovation. In 2018, China's elderly dependency ratio reached 16.8, the aging population coefficient reached 11.9. The aging of the population has hindered China's technological innovation. How to reduce the negative impact of aging on technological innovation and constantly improve the ability of technological innovation is a problem worth paying attention to. In order to alleviate the negative impact, this article makes the following recommendations:

(1) For the positions requiring rich experience, the working years can be extended appropriately, such as reemployment of retired technical personnel. In this way, the effect of learning by doing can be brought into full play. (2) The government needs to balance the expenditures of pensions and R&D funds to improve the scientific nature of government funds management. To prevent the expansion of the pension gap caused by the aging population from reducing the government's financial expenditure on R&D. In addition, the government should encourage cooperation between enterprises, universities, research institutions and financing to promote diversification of R&D funding sources. (3) We should pay attention to innovation education. Talents are the main body of innovation and give full play to the innovation vitality of high-quality labor force. Only with more innovative talents can a region and a country truly realize independent innovation.

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