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Research on the impact of population aging on the development of digital economy

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Abstract: *Under the background of aging and rapid development of digital economy in China, the academic circles pay little attention to the aging of population and the development of digital economy. Based on the panel data of 30 provinces in China from 2013 to 2020, this paper empirically analyzes the impact of population aging on the development of digital economy through a fixed effect model. It is found that population aging can significantly promote the development of digital economy, and it still has a significant impact after the test of instrumental variables. Mechanism test shows that population aging mainly improves the development of digital economy by improving the level of scientific and technological innovation. The adjustment effect shows that the level of human capital will strengthen the role of population aging in promoting the digital economy. Heterogeneity analysis shows that the role of population aging in promoting digital economy is stronger in the central and western regions than in the eastern regions.*

Keywords: *Population ageing, Digital economy, Intermediary effect.*

1. Introduction

In recent years, China's digital economy has developed rapidly, and the scale of the global digital economy will continue to expand. The digital economy has changed the traditional relationship between individuals, enterprises and society [1]. According to the white paper on the development of China's digital economy released by the Chinese Academy of information technology, the scale of China's digital economy has reached 39.2 trillion yuan in 2020, accounting for 38.6% of GDP. The digital economy has gradually become the source of China's national economic development. However, the development of China's digital economy will be affected by many factors. In recent years, China's population development has entered a new normal, that is, the population growth rate has decreased, the working age population has decreased, the population aging has accelerated, the population quality has improved, and the urban-rural distribution pattern of the population has changed [2]. Since 2000, the proportion of China's population over 65 years old has accounted for 7%, which also shows that China's demographic dividend has disappeared and has officially entered an aging society. With the deepening of population aging, some problems are also highlighted. According to the micro report of the digital life of the elderly in the post epidemic era released by Ali Research Institute in 2020, the aging of China's population shows a superposition effect with the accelerated development of the digital economy. This paper studies the impact of population aging on the development of digital economy from the perspective of population aging. The marginal contributions of this paper are as follows: first, this paper confirms the positive role of population aging on the development of digital economy, and further expands the original related theories. Second, many existing literatures mainly focus on the digital economy as the background of the times. The research scope is wide and scattered, and no one takes the digital economy as a research variable. This paper brings the population aging and the development of the digital economy into the same analysis framework to study the impact of population aging on the digital economy.

2. Theoretical analysis and research hypothesis

2.1 The impact of population aging on the development of digital economy

Domestic research on the impact of population aging on the development of digital economy is still quite few. This paper makes the following assumptions: on the one hand, population aging may not be

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conducive to the development of digital economy. With the deepening of population aging, the proportion of aging population also increases. The risk aversion of the elderly and the decline of learning ability will reduce their willingness to apply new digital products. For example, the elderly characteristics of the target group will reduce the use of digital finance [3]. On the other hand, the aging of the population may be conducive to the development of the digital economy. With the increase of the proportion of the elderly population, the corresponding elderly population will also generate corresponding demand for digital products, and the government will pay more and more attention to the elderly care industry, which will force some financial science and technology companies to develop corresponding digital products suitable for the elderly. Therefore, this paper puts forward the following assumptions:

H0: population aging will inhibit the development of digital economy.

H1: population aging will promote the development of digital economy.

2.2 Mechanism of population aging affecting the development of digital economy

2.2.1 Intermediary Effect

Technological innovation is an important driving force for the development of digital economy, and aging will have an impact on technological innovation. On the one hand, the work experience accumulated by the elderly labor force through learning by doing will make up for the decline in productivity caused by the decline of their cognitive ability, and if the rich experience and mature skills of the elderly complement the new knowledge of the young, it will promote innovation activities [4]. On the other hand, aging will lead to labor scarcity, which will force enterprises to change production mode, increase investment in technological innovation, and replace human labor through machine production, which is conducive to technological innovation and promote the development of digital economy [5]. Therefore, this paper puts forward the following assumptions:

H2: population aging will promote the development of digital economy by promoting technological innovation.

2.2.2 Regulatory Effect

Human capital accumulation effect. With the increasing aging of the population, on the one hand, the mature labor force will increase, which is equivalent to increasing the proportion of labor force with work experience [6]; On the other hand, the extension of life expectancy increases the benefits of education, which will encourage young people to increase the number of years of education and increase the accumulation of human capital [7]. The accumulation of human capital will increase the number of talents in digital economy related industries, and then promote the development of digital economy. Therefore, this paper puts forward the following assumptions:

H3: the accumulation of human capital will promote the role of population aging in promoting the development of digital economy.

2.3 The heterogeneity of population aging affecting the development of digital economy.

China is a country with unbalanced regional economic development. Therefore, the impact of population aging on the development of digital economy is likely to be heterogeneous due to regional differences. On the one hand, China's population aging is characterized by regional differences between the East and the west, and there are also obvious differences in the development of digital economy in the East and the central and western regions, which to some extent shows that there may be differences in the impact of population aging on the development of digital economy in different regions. There are also obvious differences in the per capita educational capital and scientific and technological innovation level between the eastern region and the central and western regions. Therefore, this paper puts forward the following assumptions:

H4: the impact of population aging on the development of digital economy is heterogeneous in different regions.

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3. Research design

3.1 Source of data

The data of this paper comes from the Chinese National Bureau of statistics, wind database, China Economic and social big data research platform and China Statistical Yearbook.

3.2 Variable description

1) Explained variable: digital economic development index (DE). This paper constructs the digital economic development index by principal component analysis after standardization through 15 specific variables in the three dimensions of digital economic infrastructure, digital industrialization and industrial digitization. The index system is shown in Table 1.

Table 1: Digital economy development system

First Order Dimension	Second Dimension	Indicator description	Weight
Digital Economy Infrastructure	Internet penetration	Proportion of Internet users in permanent population (%)	0.05
	Telephone penetration	(Total number of telephones (including mobile phones) / total population of Administrative Region) ×100 (units)	0.03
	Long distance optical cable line length	Long distance optical cable line length (10000 km)	0.05
	Internet broadband access port	Internet broadband access ports (10000)	0.11
	Number of Internet domain names	Number of Internet domain names (10000)	0.07
Digital industrialization	Digital industry practitioners	Average number of employees in information transmission, software and information technology service industry at the end of the year (person times)	0.07
	Software business income	Software business income (10000RMB)	0.08
	Per capita information technology service charge	Per capita information technology service charge (RMB/ person)	0.03
	Total telecom services	Total telecom business (100 million RMB)	0.09
Industrial digitization	E-commerce sales	E-commerce sales (100 million RMB)	0.09
	Enterprise informatization level	Proportion of enterprises adopting information management (%)	0.03
	Enterprise website coverage	Proportion of enterprises with websites (%)	0.02
	Digital inclusive financial index	Peking University Digital inclusive financial index	0.05
	Number of Express Services	Express delivery volume (10000 pieces)	0.10
	Number of businesses in the digital economy	Number of legal entities in information transmission, computer service and software industry	0.10

2) Core explanatory variable: the dependency ratio of the elderly (Ag), expressed by the ratio of the population over 65 to the working population. The dependency ratio of the elderly population can measure the burden of the working population on the elderly population. The corresponding aging rate

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is the ratio of the elderly population to the total population (ag2). China's aging shows a trend of decreasing the proportion of the working population and increasing the dependency ratio of the elderly [8]. Therefore, in the benchmark regression, this paper uses the dependency ratio of the elderly population for regression, and uses the proportion of the elderly population in the total population as an alternative test in the robustness analysis.

3) Intermediary variables and Regulatory variable: (1) scientific and technological innovation (Tech) is measured by the R & D expenditure of each province. Because the value is large, it is standardized, and the data is from the China Science and technology statistical yearbook. (2) Human capital level: years of education per capita (EDU): measured by years of education per capita, years of education per capita = {(number of primary school population aged 6 and over ×6) + (Number of junior high school population aged 6 and over ×9) + (Number of high school population aged 6 and over ×12) + (Number of university population aged 6 and over ×16)}/ Total number of persons aged 6 and over.

4) Control variables: (1) economic development level (ED): measured by the natural logarithm of per capita GDP; (2) Material capital investment (INV): measured by the proportion of fixed asset investment in GDP; (3) Financial development level (fsize): measured by the ratio of total bank deposits and loans at the end of each province to GDP; (4) Infrastructure construction level (INF): geometric average of mileage of grade highway and railway per square kilometer; (5) Foreign investment level (FDI): foreign direct investment is converted into RMB, and then the natural logarithm is taken; (6) Regional population density (TPD): local resident population / local area per square kilometer, and then take the natural logarithm; (7) Young dependency ratio: the ratio between the number of people aged 0-14 and over and the working population. The young dependency ratio will affect the labor supply of the country in the future and the development of digital economy. (8) Capital formation rate (INR) local total capital expenditure / GDP calculated by expenditure method. The descriptive statistics of variables are shown in Table 2.

Table 2: Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max
DE	240	0	0.75	-0.838	3.914
Ag	240	15.207	3.646	8.8	25.5
Tpd	240	5.473	1.297	2.068	8.281
Fsize	240	3.148	0.959	1.687	6.817
Lnv	240	0.862	0.3	0.198	1.597
Inf	240	0.158	0.094	0.014	0.409
Lnr	240	0.644	0.212	0.369	1.485
Young	240	23.002	6.221	11.7	37.17
Fdi	240	17.725	1.564	12.715	20.811
Ed	240	10.87	0.412	10.003	12.009
Edu	240	9.314	0.888	7.514	12.681
Tech	240	0	1	-0.861	4.417

3.3 Model Setting

3.3.1 Benchmark regression

Double fixed effect model: in order to measure the impact of population aging on digital economy and avoid errors caused by the influence of some variables affected over time, this paper adopts a two-way fixed effect model for analysis. This paper sets the following measurement model:

$$De_{it} = \beta_0 + \beta_1 Ag_{it} + \delta_j X_{ijt} + \mu_i + \lambda_i + \varepsilon_{it} (1)$$

In the above formula subscript i and subscript t represent provinces and times, respectively. De_{it} represents the digital economic index for the i province in the t year. AG_{it} represents the population ageing level of i provinces in t Year. $\delta_j X_{ijt}$ is the control variable, and j represents the different control variables. μ_i is the area effect and λ_i is the time effect. ε_{it} is a random perturbation term.

3.3.2 Model of intermediary effect

In order to test the transmission mechanism of population aging on digital economy, that is, whether the intermediary effect exists. In this paper, First, we use stepwise regression method to test the mediating

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effect. Secondly, the robustness is tested by Sobel test. The econometric model is constructed as follows:

$$De_{it} = \alpha_0 + \alpha_1 Ag_{it} + \delta_{1j} X_{ijt} + \mu_{1t} + \varepsilon_{1it} (2)$$

$$Z_{it} = \beta_0 + \beta_1 Ag_{it} + \delta_{2j} X_{ijt} + \mu_{2t} + \varepsilon_{2it} (3)$$

$$De_{it} = \gamma_0 + \gamma_1 Ag_{it} + \gamma_2 Z_{it} + \delta_{3j} X_{ijt} + \mu_{3t} + \varepsilon_{3it} (4)$$

Where Z_{it} is the intermediate variable. If α_1 is significantly positive and β_1 is significantly positive, then the mediator effect is significant. If γ_1 is not significant at this point, then the mediator effect is called the complete mediator. If γ_1 is significant but smaller than α_1, then it is called a partial mediator.

3.3.3 Regulatory Effect Model

In order to test Hypothesis 3, the following econometric model is set up in this paper:

$$De_{it} = \beta_0 + \beta_1 Ag_{it} + \beta_2 e\,du_{it} + \beta_3 c\_Ag_{it} \times e\_du_{it} + \delta_{4j} X_{ijt} + \mu_{4i} + \lambda_{4i} + \varepsilon_{4it} (5)$$

Where $\mathrm{e\,d}u_{it}$ is the level of human capital and $c\_Ag_{it} \times \mathrm{e\_d}u_{it}$ is the Regulatory variable, it is the value of Ag_{it} and $\mathrm{e\,d}u_{it}$ cross-multiplied. In order to explain the meaning of model Coefficients, both Ag_{it} and $\mathrm{e\,d}u_{it}$ are treated centrally in this paper.

4. Empirical results and analysis of the model

4.1 Benchmark regression

In order to alleviate the volatility of data and the possible heteroscedasticity problem, this paper logarithmically processes the economic development level, foreign direct investment level and regional population density in the control variables. According to the results of Hausman test, this paper selects the fixed effect model for benchmark regression. First of all, it examines the direct effect of population aging on the development of digital economy. Where de represents the development level of digital economy, and the specific empirical results are shown in Table 3. Among them, (1) is a mixed regression without considering time effect and regional effect; (2) The formula is the fixed effect regression considering the regional effect; (3) The formula is the fixed effect regression result considering both time effect and regional effect. It is not difficult to see that the results of the three regression show that population aging has a positive and significant effect on the development of digital economy, and all have passed the significance test. In model (3), the coefficient of population aging on the development of digital economy is 0.037, that is, when the population aging increases by 1 unit, hypothesis H1 is preliminarily verified.

Table 3: Results of baseline regression

	(1)	(2)	(3)
VARIABLES	DE	DE	DE
Ag	0.029***	0.072***	0.037**
	(2.859)	(5.250)	(2.077)
Control Variables	YES	YES	YES
Observations	240	240	240
R-squared	0.746	0.931	0.941
Year Fixed	NO	NO	YES
Area Fixed	NO	YES	YES

t-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2 Endogenous analysis

In the previous analysis, the fixed effect model is used for regression analysis. Although the time effect is controlled and enough control variables are added, there may still be the problems of missing variables and reverse causality, resulting in the unreliability of the previous analysis. In order to further alleviate endogeneity, this paper selects the number of elderly care beds in a region and the lag period of the core explanatory variable as instrumental variables for analysis. An instrumental variable needs to

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satisfy both exogenous and correlation conditions. On the one hand, with the increasing population aging rate in a region, the demand for the number of elderly care beds will also increase, and the lag of population aging in one period itself will affect the degree of population aging in the next period. Therefore, these two instrumental variables are consistent with correlation. On the other hand, there is no direct relationship between the number of elderly care beds in a region and the development of digital economy, while the development degree of digital economy in the current period and other random disturbance items themselves will not affect the degree of population aging in the previous period, so these two instrumental variables also meet the exogenous conditions. Table 4 below shows the regression results of instrumental variables.

Table 4: Regression results for tool variables

	(1) FE	(2) IV
VARIABLES	DE	DE
Ag	0.037**	0.097**
	(2.077)	(2.146)
Control Variables	YES	YES
Observations	240	210
R-squared	0.941	0.771
Year Fixed	YES	YES
Area Fixed	YES	YES

t-value in parentheses

4.3 Analysis of the population ageing's impact on the digital economy

4.3.1 Analysis of intermediary effect

In order to further analyze how population aging affects the development of digital economy and find out the transmission mechanism, this paper uses the method of Hayes to test the intermediary effect, and uses the stepwise regression method to verify whether technological innovation is the intermediary variable of population aging affecting digital economy. The robustness test is carried out by bootstrap and Sobel methods. The results of intermediary regression and Sobel are shown in Table 5.

Table 5: Stepwise regression and Sobel test

	(1)	(2)
VARIABLES	Tech	DE
Tech		0.722***
		(25.024)
Ag	0.037**	0.011
Control Variables	(2.024) YES	(1.479) YES
Sobel	0.0264** (2.024)	
Observations	240	240
R-squared	0.952	0.986
Year Fixed	YES	YES
Area Fixed	YES	YES

t-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

From the regression of the model (1) in Table 5 above, it can be seen that there is a positive and significant relationship between population aging and technological innovation, while putting technological innovation into the model in formula (2), it is found that the variables of population aging that had a positive and significant relationship with digital economy are no longer significant, while there is a positive and significant relationship between technological innovation and the development of digital economy, which shows that technological innovation is the medium of population aging affecting digital economy, There is an intermediary effect. According to Sobel, the coefficient is significantly positive, which is consistent with the conclusion of stepwise.

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4.3.2 Regulation Effect Analysis

The above discusses the intermediary effect of population aging on the development of digital economy. Next, in order to test H 3, this paper sets up a regulation effect model and adds human capital investment to the regression model. In order to facilitate the interpretation of logarithm, the interaction term in the model is the multiplication of population aging and human capital investment after centralization. Its economic meaning is that when the human capital takes the average value of the sample, what is the impact of each unit of population aging on the development of digital economy. The regression results of regulatory effects are shown in Table 6.

Table 6: Regression of regulatory effect

	(1)	(2)
VARIABLES	DE	DE
Ag	0.037**	0.026
	(2.077)	(1.367)
Edu		0.037
		(0.448)
c_Ag×c_Edu		0.014**
		(2.203)
Control Variables	YES	YES
Observations	240	240
R-squared	0.941	0.943
Year Fixed	YES	YES
Area Fixed	YES	YES

t-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

According to the regression results of regulatory effect in Table 6, the regulatory effect (c_Ag ×c_Edu) was 0.014 and passed the significance test. It shows that per capita education capital plays a positive regulatory role in the process of population aging affecting the development of digital economy. Per capita educational capital will promote the positive impact of population aging on the development of digital economy. That is, the increase of per capita educational capital will strengthen the positive effect of population aging on the development of digital economy.

5. Further analysis

5.1 Robustness test

Table 7: Robustness test

	(1) Benchmark regression	(2) Replacement sample interval	(3) Replace the population ageing variable	(4) Tail Tuck
VARIABLES	DE	DE	DE	DE
Ag	0.037**	0.043***		0.040**
	(0.018)	(0.011)		(0.018)
Ag2			0.061**	
			(0.026)	
Control Variables	YES	YES	YES	YES
Observations	210	210	180	180
Adjusted R-squared	0.941	0.960	0.942	0.942
Year Fixed	YES	YES	YES	YES
Area fixed	YES	YES	YES	YES

t-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In order to verify whether the impact of population aging on the development of digital economy is

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stable, this paper uses the proportion of the elderly population in the total population to replace the dependency ratio of the elderly population, reduces the sample interval (delete the samples in 2019 and 2020), and shrinks the tail of variables to test the robustness. The results of the robustness test are shown in Table 7: according to the results of the robustness test, when the core explanatory variables are replaced, the population aging still has a positive and significant relationship with the development of digital economy, and the coefficient increases slightly. When the sample interval is replaced and the tail is reduced by 1%, the population aging coefficient still has a positive and significant relationship with the development of digital economy, which has passed the significance test. As mentioned in the summary, this paper believes that population aging has a positive promoting relationship with the development of digital economy, and the result is stable.

5.2 Heterogeneity analysis

As China is a country with a vast geographical area, the imbalance of economic development between the eastern and central and western regions is obvious. Therefore, it is necessary to test the heterogeneity between the eastern and central and western regions. This paper divides samples into the eastern and central and western regions; the dummy variable is 1 in the eastern region and 0 in the central and western regions. Because the coefficients of grouped regression may have the problem of overlapping confidence intervals, the regression coefficients cannot be directly compared. Therefore, Fisher combination test is introduced to test whether there are significant differences in the heterogeneity of different regions and different aging degrees. The results of regression and inter group difference test are shown in table 8.

Table 8: Heterogeneity test

	(1) Eastern Region	(2) Central and Western regions
VARIABLES	DE	DE
Ag	-0.030	0.045***
	(0.029)	(0.015)
Control Variables	YES	YES
Observations	104	136
R-squared	0.955	0.963
Year Fixed	YES	YES
Area Fixed	YES	YES

t-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

According to Table 8, we find that the impact of population aging on digital economy is significantly positive in the central and western regions, and the coefficient of population aging is 0.045, which has passed the significance test, but not in the eastern region; It shows that different regional distribution has a significant impact on digital economy. The possible reason is that the eastern region has attracted migrant workers from the central and western regions due to its economically developed advantages, and most of these migrant workers are mainly migrant workers. Migrant workers' knowledge and skills cannot be improved rapidly in a short time, and may not be able to make a great contribution to the development of digital economy. At the same time, the acceptance of migrant workers will also alleviate the degree of aging in the eastern region, which will weaken the impact of population aging on the development of digital economy. The rapid development of population aging in the central and western regions and the transfer of young people to the east also promote the development of digital economy.

6. Conclusion

Based on the provincial panel data from 2013 to 2020, this paper constructs an index evaluation system based on the three dimensions of "digital economic infrastructure, industrial digitization and digital industrialization", measures and evaluates the development indicators of digital economy in various regions of China with the help of principal component analysis, and constructs an econometric model for Empirical Analysis on the role of population aging in digital economy. The study found that: first, population aging can significantly promote the development of China's digital economy, but there is regional heterogeneity in the degree of impact. The role of population aging in promoting the development of digital economy is more significant in the central and western regions. The results of

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mechanism test show that population aging can promote the development of digital economy through increasing human capital accumulation and accelerating technological innovation. Based on the above conclusions, this paper obtains the following policy enlightenment: (1) Because the development level of digital economy and the degree of aging are different among regions, different policies should be formulated according to local conditions. For the eastern region, too many migrant workers may increase the burden of local development of digital economy. Therefore, we need to adjust the policy of migrant population and optimize the population structure. Make it possible to develop the digital economy well. (2) Improve the level of human capital, build a multi-level education platform by strengthening education and skill training, so that people of different ages and educational backgrounds can find their own learning and training platform, so as to expand the stock of human capital. (3) To improve the level of technological innovation, governments at all levels should provide policy support and financial guarantee for innovation activities, encourage colleges and universities to carry out scientific and technological innovation, especially scientific research innovation in basic science, and apply the latest research results to the production of enterprises, so as to accelerate the process of technological innovation forced by population aging and promote the development of digital economy.

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