WEP Warwick Evans Publishing

Transactions on Economics, Business and Management Research
ISSN: 2960-1789, eISSN: 2960-2254 | Volume 7
EDMI 2024

The Impact of Digital Economy on Enterprise Radical Innovation and Its Mechanism Analysis: Based on the Empirical Data of A-Share Listed Companies

Chen Chen

School of Statistics and Data Science, Jiangxi University of Finance and Economics, Nanchang 360000, China

2191687439@qq.com

Abstract. The digital economy provides new impetus to enterprise innovation and is of great significance to the improvement of enterprise's market competitiveness. Considering the availability of data, the article uses the data of China's A-share listed companies from 2011-2019 to explore the impact of the digital economy on radical innovation using a two-way fixed-effects model, and use mediating effect test to study its mechanism of action and study its heterogeneity. The results show that, first, the digital economy can significantly promote enterprise radical innovation, and for every 1-unit increase in the digital economy, enterprise radical innovation increases by 43.2%. Second, a partial mediating role of management's digital orientation is in the innovation promotion effect. Third, there is significant heterogeneity in the promotion effect of innovation in terms of the nature of property rights, the nature of technology, enterprise scale, and human capital. Based on this, this article suggests promoting enterprise digitization and encouraging innovation in SOEs.

Keywords: Digital Economy; Radical Innovation; Mediating Effect; Digital Transformation.

1. Introduction

Innovation activates new digital kinetic energy and helps to pursue new quality productivity. The State Council issued the "State Council on the issuance of the 14th Five-Year Plan for the Development of the Digital Economy" mentioned that the digital economy provides a strong impetus for the sustained and healthy development of society. The rise of the digital economy has accelerated the transformation of the market, and enterprises need to continue to innovate to adapt to market changes. Innovation, as the core of sustainable development of enterprises, can help enterprises continuously adapt to changes in market demand. and help them survive in the market competition. Innovation is categorized into radical innovation and incremental innovation, in which radical innovation requires more capital investment and innovation time than incremental innovation. For enterprises, radical innovation is a double-edged sword for enterprises to open up new markets and enhance their core competitiveness while requiring them to undertake greater risks. Therefore, it is of both practical and theoretical significance to study the impact of digital economy on radical innovation and clarify its mechanism.

In order to deepen the research of innovation theory, the academic community categorizes innovation according to the intensity, which is divided into incremental innovation and radical innovation. Incremental innovation is an improvement on existing technology, while radical innovation is more intense than incremental innovation and is often a transformational change. Scholar Fu Yuxiu[1] believes out radical innovation is the fundamental way for late-developing countries and enterprises to realize economic catching up and leapfrogging. Therefore, radical innovation can bring greater competitiveness to enterprises. Referring to the viewpoints of Fu Yuxiu[1], this paper defines radical innovation as a kind of innovation that leads to a huge leap in the main indicators of product performance, which has a decisive impact on market rules, competitive situation, industrial layout and even leads to industrial reshuffling.

From the point of view of existing research, the research on the impact of digital economy on innovation can be broadly categorized from two aspects. One is that it can be categorized into the impact of digital economy on enterprise innovation and the study of digital economy on regional innovation from the macro and micro perspectives. The second is that it can be roughly categorized from the perspective of different attributes and characteristics of innovation into the impact of the digital economy on technological innovation, the impact of the digital economy on green innovation, the impact of the digital economy on innovation efficiency, capacity, input, and the allocation of innovation factors, etc., and is generally considered to be a positive promotion effect. Whether at the enterprise level or in regional development, it has been generally found that the digital economy has a positive promotion effect on innovation. At the level of regional development, scholars such as Liu Xinxin[2] found that the digital economy promotes regional innovation capacity through entrepreneurship using mechanism analysis. Scholars such as Li Guanglong[3] found that the different stages of the development of digital economy have different promotion effects,with non-linear characteristics. Scholar Yin Long[4] and other scholars believe that the digital economy can promote China's total factor productivity, and innovation efficiency plays a mediating role. From the perspective of enterprises, scholar Li Chunmei[5] believes that the enterprise's technology distance to frontier in the innovation effect of the digital economy is a significant "inverted U" type of moderating effect. Scholars such as Song Jing[6] believe that the digital economy has a positive effect on the quality of enterprise innovation by promoting the upgrading of human capital and improving R&D capabilities. Scholars such as Zhao Jing[7] and others believe that the digital economy has a double threshold effect on the positive promotion of enterprise innovation boundary.

In summary, there are more studies on the impact of digital economy on different attributes and characteristics of innovation. Referring to Li Chunmei's study, innovation is categorized into radical innovation and incremental innovation according to the difficulty of innovation. There are fewer studies on the impact of digital economy on radical innovation and incremental innovation. Therefore, this paper will be based on the panel data of A-share listed companies from 2011-2019, and firstly use OLS method to study the impact of digital economy on radical innovation of enterprises and analyze the heterogeneity for different aspects. And then the mediation effect test is applied to study the influence path. The conclusions of the study can provide a reference basis and strategic inspiration for enterprises to adapt to the digital economy and utilize the digital economy to improve their innovation results.

2. Theoretical Analysis and Research Hypothesis

H1: The digital economy has a positive effect on the radical innovation of enterprises.

On the one hand, based on the information asymmetry perspective. Digital economy slows down information asymmetry and improves factor mismatch. The flow of innovative factors is accelerated, and idle resources enter innovative enterprises[8]. As the digital economy strengthens the spillover effect of knowledge, it deepens inter-enterprise cooperation. The sharing of resources between enterprises makes the radical innovation of enterprises improve[9]. Furthermore, the application of technologies such as big data enables enterprises to gain more efficient insight into consumer demand, providing new ideas for enterprise radical innovation.

On the other hand, based on the perspective of innovation environment. The digital economy intensifies the competition among enterprises, and enterprises need to innovate continuously to maintain their competitiveness. Due to the development of the digital economy, the information infrastructure of the city has been continuously improved, and the operating costs and transaction costs of enterprises have been reduced, which improves the motivation of enterprise innovation.

H2: The digital economy has a positive effect on radical innovation in enterprises by promoting digital orientation of management

The various technologies brought about by the digital economy have led to a great increase in enterprise productivity. This has led to the digital transformation of enterprises gradually being emphasized by enterprise management. Enterprise management realizes that the application of digital technology, breaking the traditional mode of thinking, management mode can improve the productivity of enterprises. On the one hand, the management of the digital orientation makes the acceleration of enterprise productivity, there are more funds to invest in radical innovation. On the other hand, the flexible digital management is more conducive to the innovation of enterprise researchers than the traditional management, creating an atmosphere of practical new technologies and new methods, and providing impetus for radical innovation.

3. Empirical Research

3.1. Variable Selection

3.1.1. Explained Variable

The explanatory variable is enterprise radical innovation (innovation). According to China's patent application system, patents are categorized into invention-type patents, utility-type patents, and design-type patents. Invention patents usually involve new, non-obvious inventions; utility patents involve smaller improvements, generally in shape and structure; and design patents involve changes in the external aesthetics of a product (Article 2 of the Patent Law of the People's Republic of China). Since invention patents are more in line with the concept of radical innovation, this paper uses the number of invention patents of enterprises to measure the level of radical innovation. Since there are zero invention patents in enterprises, the natural logarithm is taken after adding one to the invention patents.

3.1.2. Explanatory Variable

The explanatory variable is digital economy (digital). Referring to the existing literature, regarding the economic measurement of digital economy, most scholars utilize the comprehensive indicator table. For the provincial level measurement, most scholars measure from digital infrastructure[10], industrial digitization, digital industrialization[10], digital governance, and digital citation innovation. And there is less related literature on digital economy measurement at the city level. Referring to the index system of Li Chunmei[5], Zhao Tao[11] and other studies, this paper carries out the construction of comprehensive indexes from the two aspects of digital financial inclusion and and Internet development, involving the per capita telecommunication business volume (telecom), the per capita postal business volume (postal), the number of Internet users (internet), the percentage of computer service and software employees (computer) The number of cell phone subscribers (number) and the digital financial inclusion index (index) are six indicators. The entropy weighting method is applied year by year to calculate the weight of each indicator and measure the digital economy comprehensively.

Table 1. Weight table

index	unit	Weight every one year								
		2011	2012	2013	2014	2015	2016	2017	2018	2019
telecom	Yuan	0.13	0.13	0.11	0.12	0.13	0.13	0.11	0.15	0.20
postal	Yuan	0.21	0.30	0.35	0.34	0.33	0.31	0.36	0.29	0.27
internet	Hundred people	0.26	0.20	0.15	0.15	0.15	0.14	0.11	0.11	0.10
computer	Hundred people	0.22	0.20	0.23	0.24	0.24	0.28	0.29	0.33	0.29
number		0.15	0.14	0.13	0.12	0.12	0.13	0.11	0.11	0.11
index		0.03	0.02	0.03	0.03	0.03	0.02	0.01	0.01	0.03

3.1.3. Mediator

The mediating variable is management's digital orientation (management). There is less literature on the measurement of management's digital orientation. Referring to the existing literature on the study of management orientation in enterprises, its measurement can be roughly divided into two ways, using text word frequency for measurement[12] and questionnaire scale for measurement[13]. Because of the subjectivity and tendency of questionnaire data, this paper adopts the more objective text word frequency for measurement. The ratio of digitized keywords to the total number of words in the Management Discussion and Analysis section of the annual report for each year was applied.

3.1.4. Control Variable

In order to reduce the impact of omitted variable bias on the regression results, this paper selects the following control variables: age of the enterprise (Age), on the one hand, the older the enterprise is, the more obvious the effect of organizational inertia. Its cognitive inertia and structural inertia will hinder the enterprise's radical innovation[14].on the other hand, due to the radical innovation is a larger change to the previous technology, and the older the enterprise may enter the bottleneck period of innovation, for radical innovation output is less. Enterprise size (lScale), measured by the total assets of the enterprise. Radical innovations require high capital investment and high risk. Large-scale enterprises have sufficient capital and risk-bearing capacity, and the larger the enterprise size, the more it tends to favor radical innovation. The proportion of shares held by the top ten shareholders (Share10) can measure the degree of share concentration of the company, the greater the degree of share concentration, the greater the risk of fixed commitment to innovation, so the willingness to innovate is insufficient[15]; the nature of the enterprise (Nature), state-owned enterprises variable value is go to 1, and the value of the variable of the non-state-owned enterprises is 0; assets-liability ratio (LOAR) is expressed by the total liabilities/total assets; The number of employees in a company (Number) is expressed as the total number of employees plus one and then taking the logarithm.; SA index (SA) indicates the financing constraints of the enterprise; Tobin's q-value (Q) is expressed as market capitalization/total assets; Industrial structure (Struc) is measured by the ratio of the added value of the tertiary industry to the added value of the secondary industry; and foreign investment (FDI) is measured by the ratio of the output value of the foreign-invested enterprises to the gross domestic product.

The following are descriptive statistics of the variables

Table 2. Descriptive statistic

Variable	Obs	Mean	Mariance	Min	Max
innovation	21284	1.037	1.295	0	5.303
Digital	21284	0.254	0.227	0.0240	0.864
Age	21284	10.32	7.052	1	25
lScale	21284	22.20	1.277	19.67	26.14
Share10	21284	58.33	14.99	23.33	90.17
Nature	21284	0.382	0.486	0	1
LOAR	21284	0.428	0.207	0.0520	0.906
Number	21284	7.708	1.247	4.382	11.16
SA	21284	-3.781	0.239	-4.362	-3.118
Q	21284	2.027	1.307	0.871	9.022
Struc	21284	1.485	1.003	0.420	5.169
FDI	21284	0.138	0.207	0	0.996

3.2. Data Sources

The enterprise level of this paper uses the data of A-share listed companies from 2011-2019. In order to reduce the impact of abnormal data on the empirical results, the public companies of ST type and financial industry are excluded, the abnormal values are shrink-tailed, and the samples with missing values of key variables are excluded, and finally the observed values of 3209 listed companies are obtained. The data of listed companies are obtained from CSMAR database, wind database, and CNRDS database. Data for cities are from China Regional Economic Statistics Yearbook, China Urban Statistics Yearbook, and Peking University Digital Financial Inclusion Index.

3.3. Model Setup

3.3.1. Fixed Effects Model

According to related research, a fixed-effects model is constructed with digital economy as the explanatory variable and radical innovation as the explanatory variable:

$$innovation_{ijt} = \alpha_0 + \alpha_1 Digital_{it} + \sum \alpha_m controls_{ijt} + \mu_i + \lambda_t + \varepsilon_{ijt} \quad (1)$$

where innovation denotes radical innovation of enterprises; Digital represents the level of digital economy of the city; controls denotes control variables, μ and λ are two-way fixed effects of the industry and year of the enterprise, respectively, and ε is a random error factor. i, j, and t represent the city, the enterprise, and the year, respectively.

3.3.2. Intermediary Effect

To further investigate the path of influence of the digital economy on the effect of radical innovation, a mediation effect model is constructed on the basis of benchmark regression, drawing on Wen Zhonglin and Ye Baojuan[16]. To test whether the digital economy passes the transmission mechanism of promoting radical innovation of enterprises. The following model is constructed for this purpose:

$$innovation_{ijt} = \alpha_0 + \alpha_1 Digital_{it} + \sum \alpha_m controls_{ijt} + \mu_i + \lambda_t + \varepsilon_{ijt} \quad (2)$$

$$management_{ijt} = \beta_0 + \beta_1 Digital_{it} + \sum \beta_m controls_{ijt} + \mu_i + \lambda_t + \varepsilon_{ijt} \quad (3)$$

$$innovation_{ijt} = \gamma_0 + \gamma_1 Digital_{it} + \gamma_2 management_{ijt} + \sum \gamma_m controls_{ijt} + \mu_i + \lambda_t + \varepsilon_{ijt} \quad (4)$$

4. Analysis of Empirical Results

4.1. Benchmark Regression

The following table reports the results of the regression on the impact of the digital economy on radical innovation. Both model (1) and model (2) are fixed effect regression results of digital economy on radical innovation of enterprises. Model (1) does not add control variables, and model (2) adds the control variables of company and prefecture-level city. The table below shows that the effect of digital economy on radical innovation of enterprises is significantly positive at the 1% level of significance regardless of whether control variables are added or not, indicating that the digital economy has a significant enhancement effect on radical innovation. Model (2) shows that ceteris paribus, for every 1 unit increase in the digital economy, radical innovation of enterprises improves by 43.2%. In order to solve the problem of heteroskedasticity and autocorrelation, robust clustering standard errors are used on the basis of model (2), and the clustering level is prefecture-level cities. Model (3) is the result of regression using robust clustering standard errors. The results show that ceteris paribus, for every one unit increase in the digital economy, enterprises' radical innovation improves by 43.2%.

The multicollinearity test of Model (3) shows that the variable VIF < 5, indicating that there is no multicollinearity. Thus Hypothesis 1 is proven.

Table 3. Benchmark regression result

	(1)	(2)	(3)
	innovation	innovation	innovation
Digital	0.419***	0.432***	0.432***
	(0.0378)	(0.0455)	(0.126)
Age		-0.0417***	-0.0417***
		(0.00176)	(0.00419)
lScale		0.187***	0.187***
		(0.0123)	(0.0265)
Share10		-0.00594***	-0.00594***
		(0.000602)	(0.00141)
Nature		0.219***	0.219***
		(0.0201)	(0.0619)
LOAR		-0.196***	-0.196*
		(0.0483)	(0.0963)
Number		0.131***	0.131***
		(0.0104)	(0.0242)
SA		0.00888	0.00888
		(0.0436)	(0.131)
Q		0.0520***	0.0520***
		(0.00757)	(0.0135)
Struc		-0.0606***	-0.0606*
		(0.0106)	(0.0261)
FDI		0.289***	0.289***
		(0.0444)	(0.0788)
cons	0.264***	-4.209***	-4.209***
	(0.0771)	(0.299)	(0.616)
Region	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed
N	21284	21284	21284

Enterprise age is a significant negative influence on enterprise radical innovation. Since radical innovation requires a large amount of capital investment, the innovation cycle is longer and more risky. As the age of the enterprise grows, the enterprise will be more inclined to avoid the risk, so the enterprise radical innovation activities are hindered. Enterprise size has a positive effect on radical innovation, indicating that the larger the enterprise size, the more capital the enterprise has to invest in radical innovation, so enterprise radical innovation is improved. The shareholding ratio of top ten shareholders has a significant negative effect on radical innovation. The shareholding ratio of the top ten shareholders represents the degree of share concentration of the enterprise. The more concentrated the enterprise' share, the more decision-making is influenced by subjective factors, which affects the process of radical innovation. The level of assets-liability ratio and financing constraints both have a

negative effect on radical innovation, indicating that the more debt, the more difficult to finance, and the limited funds invested in innovation, which hinders the output of radical innovation. Foreign investment in the city where the enterprise is located has a significant role in promoting radical innovation. On the one hand, foreign investment may bring advanced technology and management experience, which is favorable to enterprise innovation, and on the other hand, foreign investment brings more resources to promote enterprise innovation.

4.2. Robustness Test

Table 4. Robustness test

	(1)	(2)	(3)
	Patent acquisition	patent application	patent application
Digital	0.471***		
	(0.0815)		
DigitalPCA		0.0368***	
		(0.00997)	
L.Digital			0.438***
			(0.119)
Age	-0.0263***	-0.0423***	-0.0419***
	(0.00308)	(0.00411)	(0.00435)
lScale	0.187***	0.188***	0.206***
	(0.0220)	(0.0260)	(0.0291)
Share10	-0.00541***	-0.00593***	-0.00593***
	(0.00121)	(0.00135)	(0.00135)
Nature	0.133*	0.222***	0.270***
	(0.0529)	(0.0628)	(0.0664)
LOAR	-0.185*	-0.190	-0.201
	(0.0745)	(0.0980)	(0.106)
Number	0.0835***	0.125***	0.125***
	(0.0148)	(0.0237)	(0.0265)
SA	0.121	-0.000241	-0.0538
	(0.101)	(0.131)	(0.146)
Q	0.0416***	0.0526***	0.0562***
	(0.0101)	(0.0136)	(0.0131)
Struc	-0.0254	-0.0629*	-0.0701**
	(0.0190)	(0.0251)	(0.0233)
FDI	0.225***	0.278***	0.270***
	(0.0653)	(0.0709)	(0.0767)
cons	-3.776***	-4.154***	-4.732***
	(0.518)	(0.615)	(0.676)
Region	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed
N	20689	20689	17030

In order to further verify the conclusions of this paper, the robustness test is carried out in the following three aspects: first, replacing the explanatory variables, replacing the explanatory variable number of enterprise patent applications with the number of enterprise patents obtained. The results are shown in model (1). Second, the entropy weight method to construct the comprehensive index of digital economy replaces the principal component method to construct the comprehensive index of digital economy. The results are shown in model (2). Third, considering that the impact of digital economy on innovation may play a role in the next year, the digital economy lagged one period as an explanatory variable. The results are shown in model (3). The results of the robustness test are shown in the following table, from which it can be concluded that the impact of digital economy on radical innovation is significantly positive, which is consistent with the results of the benchmark regression, indicating that the results of the benchmark regression are robust.

4.3. Mediation Effect

Table 5. Mediation effect test

	(1)	(2)	(3)
	innovation	strength	innovation
Digital	0.423***	0.0503***	0.326**
	(0.123)	(0.00717)	(0.112)
strength			1.937***
			(0.181)
Age	-0.0423***	-0.000485*	-0.0414***
	(0.00418)	(0.000242)	(0.00401)
lScale	0.189***	-0.00276**	0.194***
	(0.0262)	(0.00100)	(0.0258)
Share10	-0.00595***	-0.000322**	-0.00533***
	(0.00136)	(0.000100)	(0.00129)
Nature	0.223***	-0.00558	0.234***
	(0.0627)	(0.00311)	(0.0599)
LOAR	-0.189	-0.00265	-0.183
	(0.0978)	(0.00758)	(0.102)
Number	0.124***	0.0102***	0.105***
	(0.0238)	(0.00133)	(0.0220)
SA	-0.00305	-0.00818	0.0128
	(0.132)	(0.00558)	(0.128)
Q	0.0528***	0.00381***	0.0455***
	(0.0137)	(0.00101)	(0.0132)
Struc	-0.0609*	0.00158	-0.0640**
	(0.0255)	(0.00140)	(0.0235)
FDI	0.261***	0.00546	0.251***
	(0.0725)	(0.00680)	(0.0699)
cons	-4.238***	-0.0605	-4.121***
	(0.612)	(0.0317)	(0.597)
Region	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed
N	20689	20689	20689
Boostrap		P<0.01	

This paper further investigates the transmission mechanism of digital economy on enterprises' radical innovation. This paper uses the mediation effect test to examine whether the digital economy affects enterprises' radical innovation through management digital orientation as shown in the table below, where model (2) indicates that peteris paribus, for every unit change in the digital economy, management digital orientation increases by 0.05 units. At 1% level of significance, digital economy significantly increases management digital orientation. It indicates that management is influenced by the digital economy and increasingly focuses on the digital transformation of the enterprise. The digital economy brings big data technology and so on to the enterprise, which improves the productivity of the enterprise and makes the management digital orientation of the enterprise increase. As shown in model (3), the digital economy and management digital orientation are used to regress on enterprise radical innovation. The results show that at the 1% significance level, management digital orientation has a significant contribution to enterprise radical innovation. Meanwhile, digital economy also has a significant contribution to enterprise radical innovation. It indicates that management's digital orientation plays a partial mediating role in the effect of digital economy on enterprise radical innovation. For the reliability of the mediation effect test, this paper further examines the results using Boostrap test, and the result is p-value <0.01, indicating that the results are reliable. Therefore, hypothesis 2 is proved.

4.4. Heterogeneity

4.4.1. Enterprise Property Attributes

Table 6. Heterogeneity of property right attribute

	(1) SOE innovation	(2) non-SOE innovation
Digital	0.212	0.491***
	(0.221)	(0.106)
Age	-0.0318***	-0.0499***
	(0.00837)	(0.00472)
lScale	0.241***	0.180***
	(0.0331)	(0.0500)
Share10	-0.00661**	-0.00555***
	(0.00206)	(0.00158)
LOAR	-0.204	-0.245*
	(0.176)	(0.0979)
Number	0.0858*	0.141***
	(0.0344)	(0.0266)
SA	0.0784	-0.000226
	(0.257)	(0.105)
Q	0.0488	0.0606**
	(0.0350)	(0.0201)
Struc	-0.0843	-0.0352
	(0.0467)	(0.0198)
FDI	0.243	0.269**
	(0.140)	(0.0868)
cons	-4.804***	-4.047***
	(1.153)	(0.961)
Region	Fixed	Fixed
Time	Fixed	Fixed
N	7935	12754

In this paper, the sample is divided into state-owned enterprises and non-state-owned enterprises according to the nature of property rights of enterprises, and the heterogeneity analysis is conducted, and the regression results are shown in the table below. From (1), it can be seen that the digital economy has no significant effect on the radical innovation of state-owned enterprises. From (2), it can be seen that the digital economy has a significant effect on radical innovation of non-state-owned enterprises, and its coefficient is positive at 1% significance level. This indicates that the digital economy only has an impact on radical innovation of non-SOEs. On the one hand, it may be due to the fact that the competition among non-state-owned enterprises is more intense than state-owned enterprises. The digital economy accelerates technological upgrading, and non-state enterprises are forced to accelerate the speed of enterprise innovation in order to gain an advantage in market competition. On the other hand, the government may provide more resources as well as support to SOEs. On the contrary, it makes the state-owned enterprises less aware of the market competition crisis, which results in the inefficiency of the enterprises and hinders the radical innovation of the enterprises. At the same time, the management of non-state-owned enterprises is more flexible than the management of state-owned enterprises, and the response to the market is more rapid. State-owned enterprises are affected by the management system, making decisions more slowly, hindering the process of innovation.

4.4.2. Enterprise Technological Attributes

Table 7. Heterogeneity of technical attributes

	(1) high-tech innovation	(2) non-high-tech innovation
Digital	0.472**	0.225
	(0.149)	(0.129)
Age	-0.0621***	-0.0256***
	(0.00562)	(0.00371)
lScale	0.239***	0.0994***
	(0.0556)	(0.0293)
Share10	-0.00600**	-0.00391***
	(0.00197)	(0.00110)
Nature	0.453***	0.00988
	(0.0960)	(0.0467)
LOAR	-0.318*	-0.193
	(0.126)	(0.108)
Number	0.275***	0.0631**
	(0.0403)	(0.0202)
SA	0.175	-0.0424
	(0.165)	(0.0994)
Q	0.0771***	0.0175
	(0.0185)	(0.0133)
Struc	-0.0761*	-0.0203
	(0.0300)	(0.0269)
FDI	0.377**	0.127
	(0.122)	(0.0810)
cons	-5.112***	-1.765**
	(0.967)	(0.658)
Region	Fixed	Fixed
Time	Fixed	Fixed
N	11010	9679

In this paper, we refer to the approach of Peng Hongxing[17] to categorize enterprises into high-tech enterprises and non-high-tech enterprises, to verify the differences in the innovation promotion effect of the digital economy on different enterprises, and the regression results are shown in the table below. With (2), it can be seen that for non-high-tech enterprises, the digital economy does not have a significant promotion effect on their radical innovation. And with (1) it can be seen that for high-tech enterprises, digital economy has a significant promotion effect on their radical innovation. It indicates that the digital economy has more significant promotion effect on the innovation of high-tech enterprises than non-high-tech enterprises. The reason may be that high-tech enterprises already have the foundation of R&D and high-end R&D equipments, etc. The reason may be that high-tech enterprises are more inclined to put their own R&D equipments on the market. At the same time, high-tech enterprises are more inclined to invest capital and other factors of production in R&D. The R&D atmosphere brought by enterprise attributes is more favorable to high-tech enterprises. The R&D atmosphere brought by enterprise attributes is more favorable for enterprises to use the digital economy for innovation. As for traditional enterprises, due to the lack of technological foundation, the application of new technologies is not enough ability and motivation, resulting in the promotion effect of the digital economy on their radical innovation is not obvious.

4.4.3. Human Capital

Table 8. Human capital heterogeneity

	(1) high human capital innovation	(2) Low human capital innovation
Digital	0.460***	0.0525
	(0.137)	(0.115)
Age	-0.0414***	-0.0524***
	(0.00446)	(0.00891)
lScale	0.192***	0.0827
	(0.0264)	(0.0614)
Share10	-0.00628***	-0.00164
	(0.00142)	(0.00236)
Nature	0.209**	0.320**
	(0.0630)	(0.119)
LOAR	-0.190	-0.137
	(0.102)	(0.211)
Number	0.133***	0.0662
	(0.0252)	(0.0506)
SA	0.00202	-0.173
	(0.138)	(0.261)
Q	0.0536***	0.0126
	(0.0160)	(0.0271)
Struc	-0.0673*	0.00287
	(0.0272)	(0.0332)
FDI	0.275***	0.185
	(0.0764)	(0.198)
cons	-4.369***	-1.798
	(0.664)	(1.215)
Region	Fixed	Fixed
Time	Fixed	Fixed
N	18878	1666

The digital economy has brought technologies such as big data technology and artificial intelligence to empower businesses, however, due to the application of artificial intelligence and other technologies, there are barriers. High-skilled people are good at utilizing new technologies to empower enterprises, while low-skilled people still have barriers in using new technologies. So the facilitating effect of digital economy on radical innovation of enterprises depends on the human capital of enterprises. In order to verify the heterogeneity of human capital, this paper takes the median number of enterprise PhDs as the cut-off point and conducts group regression, and the results are shown in the table below. From (2), the promotion effect of digital economy on innovation is not significant in enterprises with insufficient human capital. And from (1), it can be seen that in enterprises with high human capital, the digital economy has a significant promotion effect on radical innovation. The reason is that the application of the digital economy and radical innovation are characterized by higher requirements on the technical skills of human capital of enterprises. If the level of human capital of enterprises is low, enterprises cannot "absorb" the innovation promotion effect of the digital economy.

4.4.4. Enterprise Size

Table 9. Scale heterogeneity

	(1) large-scale innovation	(2) small and medium-scale innovation
Digital	0.477***	0.378**
	(0.114)	(0.138)
Age	-0.0393***	-0.0474***
	(0.00586)	(0.00397)
lScale	0.230***	0.254***
	(0.0419)	(0.0444)
Share10	-0.00741***	-0.00359*
	(0.00167)	(0.00147)
Nature	0.261**	0.210***
	(0.0847)	(0.0570)
LOAR	-0.0522	-0.177
	(0.206)	(0.0929)
Number	0.143***	0.0753**
	(0.0283)	(0.0266)
SA	-0.0883	0.0762
	(0.225)	(0.0913)
Q	0.121**	0.0385**
	(0.0379)	(0.0133)
Struc	-0.0891***	-0.0492
	(0.0236)	(0.0372)
FDI	0.320*	0.195*
	(0.127)	(0.0862)
cons	-5.911***	-5.036***
	(1.245)	(0.827)
Region	Fixed	Fixed
Time	Fixed	Fixed
N	10344	10345

In this paper, enterprises with enterprise size larger than the median are defined as large-scale enterprises, and enterprises with enterprise size smaller than the median are defined as small and medium-scale enterprises. The group regression results are shown in the table below. From (1), it can be seen that in large-scale enterprises, at 1% significance level, the digital economy has a significant contribution to the radical innovation of enterprises, and the coefficient of the digital economy is 0.477. From (2), it can be seen that in large-scale enterprises, at 5% significance level, the digital economy has a significant contribution to the radical innovation of enterprises, and the coefficient of the digital economy is 0.378. Comparing the coefficients of (1) and (2) coefficients, both in terms of the significance level and the coefficient of the digital economy, the digital economy of large-scale enterprises has a better effect on the promotion of radical innovation than that of small and medium-sized enterprises. On the one hand, since enterprises' radical innovation requires more capital investment, large-scale enterprises can invest more funds and talents in innovative R&D activities. On the other hand, large-scale enterprises have stronger risk-bearing ability. Radical innovations, on the other hand, have high risks and long cycles, which may be unaffordable for small and medium-scale enterprises, making the promotion effect not as strong.

5. Conclusion and Recommendations

5.1. Conclusion

Through the above analysis, this paper obtains the following main conclusions:

(1) The digital economy can significantly promote the radical innovation of enterprises

Based on the data of A-share listed companies and prefecture-level cities from 2011 to 2019, this paper verifies the positive promotion effect of digital economy on the radical innovation of enterprises, and the robustness test indicates that the results are reliable. The promotion effect of digital economy on enterprise radical innovation stems from the fact that digital economy mitigates the problem of market information asymmetry on the one hand, and provides an innovative environment for enterprise innovation on the other.

(2) Digital economy promotes enterprise radical innovation by facilitating management's digital orientation

In this paper, the ratio of digitized keywords to the total number of words in the Management Discussion and Analysis section of the annual report for each year is taken as an indicator of management's digital orientation. The mediation effect test is used to verify that the digital economy has a positive effect on management's digital orientation, and at the same time, management's digital orientation has a positive effect on enterprise radical innovation. Management digital orientation plays a partial mediating role in the positive effect of digital economy on innovation.

(3) There is heterogeneity in the positive effect of digital economy on enterprises' radical innovation in terms of property attributes, technology attributes, human capital, and scale.

This paper investigates the heterogeneity of the promotion effect of the digital economy through group regression. In terms of enterprise property rights attributes, for state-owned enterprises, the digital economy has no significant effect on enterprise radical innovation. For non-state-owned enterprises, the digital economy has a significant positive effect on enterprise radical innovation. In terms of enterprise technology attributes, for non-high-technology enterprises, the digital economy does not have a significant promotion effect on their radical innovation. For high-tech enterprises, the digital economy has a significant promotion effect on their radical innovation. In terms of enterprise human capital, in enterprises with insufficient human capital, the promotion effect of the digital economy on innovation is not significant. In enterprises with high human capital, the digital economy has a significant promotion effect on radical innovation. In terms of enterprise scale, the digital economy has a promotion effect on radical innovation in both large-scale enterprises and small- and

medium-scale enterprises, and the digital economy of large-scale enterprises has a better promotion effect on radical innovation than that of small- and medium-scale enterprises.

5.2. Recommendations

Based on the above conclusions, this paper puts forward the following recommendations:

(1) Enterprises should accelerate their adaptation to the digital economy and let the digital economy empower them.

Since there is a skill threshold for the application of technologies such as big data and artificial intelligence, enterprises should improve the level of human capital as well as increase the utilization rate of digital technologies by making greater efforts. On the other hand, enterprises should strengthen the digital infrastructure, build a cloud computing platform, blockchain, etc. so that the digital economy empowers enterprise innovation.

(2) Enterprise management improve the importance of the digital economy, focusing on enterprise digital transformation.

Management focus on the formation of a digital culture, advocating that employees actively learn and use digital technology, so that digital technology to assist in research and development and innovation. Formulate the corresponding enterprise digital transformation strategy, so that the digital economy for enterprise management, business operations and business decision-making empowerment, and better promote enterprise radical innovation.

(3) The government should mobilize the innovation enthusiasm of state-owned enterprises and promote the radical innovation of state-owned enterprises.

The government should establish an innovation incentive mechanism to stimulate the innovation motivation of state-owned enterprises. On the one hand, formulate relevant policies for state-owned enterprises and establish innovation incentive mechanism. On the other hand, Weaken the state-owned nature protection of state-owned enterprises, so that state-owned enterprises into the market competition, stimulate the innovation potential of state-owned enterprises.

(4) For different types of enterprises, in terms of human capital, technology, capital, etc., the government should give assistance as appropriate.

Develop corresponding talent attraction policies for enterprises with a weak level of human capital; give technical and financial assistance to enterprises with a weak level of technology and insufficient funds, establish an inter-enterprise exchange platform, strengthen inter-enterprise exchanges and cooperation, and improve the overall level of radical innovation in enterprises.

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