Is the digital economy promoting the quantity and quality of enterprise innovation——Evidence from China

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Keywords: Digital economy, Quantity of enterprise innovation, Quality of enterprise innovation, level of enterprise human capital, Financing constraints

Abstract: Based on the data of Chinese A-share listed companies from 2012 to 2020,this study establishes the fixed effects model to explore the influence of the development of digital economy on the quantity and quality of enterprise innovation and its internal mechanism.The regression results show that the development of digital economy can not only promote enterprises to increase the quantity of innovation, but also promote enterprises to improve the quality of innovation；the development of digital economy increases the quantity of innovation and improves the quality of innovation by improving the level of enterprise human capital and alleviating the financing constraints of enterprises. The digital economy has become an important driving force for enterprise innovation. We should actively promote the integration of digital economy and real economy, and give full play to the role of digital economy in improving the level of enterprise human capital and alleviating the financing constraints of enterprises, to empower China's innovation-driven strategy and promote high-quality economic development.

1. Introduction

The Fifth Plenary Session of the 19th CPC National Congress proposed that we should fully release the digital vitality and accelerate the penetration of the digital economy into all sectors of the traditional economy, to realize the deep integration of digital economy and real economy and create new advantages of China's digital economy. With a new round of global scientific and technological revolution and industrial transformation accelerating, human society has entered the era of digital economy. The development of digital economy has become a new variable changing the international competition landscape, a new opportunity for countries to build international competitiveness and a new engine to drive economic growth. Seizing the new opportunities for the digital economy will enable us to get priority in future. During the 13th Five-Year Plan period, under the background of in-depth implementation of the digital economy development strategy, China's digital economy has achieved leapfrog development and the scale of digital economy has reached to a new level. According to the statistics of The White Paper on The Development of China's Digital Economy (2021) released by the China Information and Communication Academy, the scale of China's digital economy reached 39.2 trillion yuan and accounted for 38.6% of GDP by 2020, achieving an increase of 18.6 percentage points compared with 2002. With the development of the digital economy, which is based on emerging technologies and integrated with the real economy, data has become a major factor of production and gradually replaced traditional factors of production such as labour and capital, reshaping the form of resource allocation and having a profound impact on industrial chain innovation, enterprise innovation and enterprise specialization. Therefore, how to give full play to the role of the digital economy to promote enterprise innovation for empowering China's innovation-driven strategy and promoting high-quality economic development has received extensive attention from the academic and political communities in recent years.

Previous researches on digital economy mainly focus on the following four aspects: first, the establishment and measurement of indicators of the level of digital economy development (Wang Jun et al., 2021) and the establishment and measurement of indicators of the scale of digital economy (Xu

Xianchun and Zhang Meihui, 2020); Second, the current situation of China's digital economy development (Li Yongjian, 2021), the comparison of the current situation of digital economy development in various countries (Liu Jiaqi and Ru Shaofeng, 2022) and the future development trend of digital economy (Li Xiaohua, 2019); Third, the influence of digital economy on regional development, including economic growth (Zhang Teng et al., 2021), regional innovation (Li Xue et al., 2021), total factor productivity (Yang Huimei and Jiang Lu, 2021), upgrading of industrial structure (Chen Xiaodong and Yang Xiaoxia, 2021), carbon emission (Zou Jing and Deng Xiaojun, 2022), employment quality (Qi Yudong et al., 2020), social governance (Niu Fengjuan, 2022), inclusive growth (Zhang Xun et al., 2019) and export trade (Yu Shan et al., 2021), etc. Scholars have also discussed monopoly issues caused by digital economy (Xiong Honru, 2019) and tax collection and management issues (Hu Lianqiang et al., 2019); Fourth, the influence of digital economy on enterprise development, mainly including enterprise productivity (Du Chuanzhong and Zhang Yuan, 2021), enterprise management (Qi Yudong and Xiao Xu, 2020), enterprise risk-taking level (Chen Xiaohui and Zhang Hongwei, 2021), enterprise digital transformation (He Fan and Liu Xiaoxia, 2019), and enterprise value (Li Xiaozhong, 2021), etc. However, micro empirical studies on the development of digital economy and enterprise innovation are scarce. Some literatures discuss the impact of digital transformation on enterprise innovation (Ferreira et al., 2019), and some literatures discuss the impact of digital technology application on enterprise innovation. Liu Lina and Yan Zhaokun (2021) point out that enterprises are able to quickly identify internal redundant resources by using digital technologies such as big data and block chain, and the accumulated redundant resources are diverted to the innovation activities of enterprises, which not only achieve the effective use of redundant resources, but also enhance the level of enterprise innovation.

The Fifth Plenary Session of the 19th CPC National Congress set the tone for the 14th Five-Year Plan, clearly stating that China must continue to implement the innovation-driven development strategy. Enterprise innovation which occupies the main position in the national innovation-driven development strategy is the key endogenous force of technological progress, and is the driving force of high-quality national economic development. So, as the forerunner of digital economy, does the development of digital economy in China promote enterprise innovation? If the answer is yes, does the digital economy promote the quantity or quality of enterprise innovation? What is the internal mechanism? Answering these questions will help us clarify the relationship between the development of digital economy and enterprise innovation, and also provide a basis for the implementation of China's innovation-driven development strategy. In view of this, this paper uses entropy evaluation method to measure the comprehensive index of digital economy development at the provincial level, and use data of Chinese A-share listed companies from 2012 to 2020 to establish the fixed effects model to explore the influence of the development of digital economy on the quantity and quality of enterprise innovation and its internal mechanism.

The marginal contribution of this study is as follows: First, this study analyzes the impact of digital economy on enterprise innovation level from the perspectives of macro and micro, which provides empirical evidence for the development of digital economy in each province; Second, previous empirical studies of the digital economy on enterprise innovation tend to focus on the quantity of enterprise innovation, this paper will analyse the relationship between the development of the digital economy and enterprise innovation from two analytical perspectives:quantity of enterprise innovation and quality of enterprise innovation, and provide empirical evidence that the digital economy has become a new driving force for enterprise innovation; Thirdly, this paper explores the theoretical mechanism that digital economy affects the quantity and quality of enterprise innovation by influencing the level of enterprise human capital and financing constraints, deepening the theoretical basis of existing research.

2. Theoretical Analysis and Hypothesis

2.1 Digital Economy and enterprise Innovation

With the popularization of the Internet and the wide application of the new digital technologies, the

digital economy has been deeply integrated with the real economy, stimulating the strong vitality of the digital economy and providing the possibility for the digital economy to effectively enhance the level of enterprise innovation: First, with the development of digital economy, digital technologies such as big data, block chain and artificial intelligence are applied to realize the deep integration of digital economy and real economy, and promote the transformation of enterprises to "digitization" and "intelligence" (KOHLI and MELVILLE,2019), changing the traditional operation mode and management mode of enterprises. Digital technology enables enterprises to operate faster, more accurate and more precise, and strengthens the cooperation among various departments of enterprises. When all departments of enterprises are in a coordinated system, they can further enhance the work efficiency of innovation department and promote enterprises to improve the level of enterprise innovation. The transmission of information in the form of data can effectively simplify the business process of enterprises, and promote the efficient operation of enterprises, which contribute to creating new products, new services and new business models for enterprises, reducing the cost of enterprises and improving the innovation level of enterprises (Wang Hui et al., 2021). Secondly, digital technologies make it possible for enterprises to interact with users at the millisecond level. In the real economy, the interaction between enterprises and customers is mostly achieved through "face-to-face" communication, while in the digital economy, users' information becomes data, and enterprises can directly gain information on users' needs with the help of Internet and digital technology, which enables enterprises to obtain comprehensive and dynamic information on users' needs with low cost and high efficiency compared to the real economy. Enterprises can make immediate adjustments to innovation directions, processes and strategies based on users' feedback, improving the operational efficiency of the enterprise innovation system and promoting enterprises to increase the quantity of enterprise innovation and improve the quality of enterprise innovation (Xiao Jinghui, 2020). Third, with the development of digital economy, the decentralized network effect and platform effect break through the geographical limitation and time constraint of traditional market (Huang Peng and Chen Liang, 2021), promote market integration and expand the scope and speed of enterprises' acquisition and dissemination of new technologies and knowledge. On the one hand, enterprises can quickly acquire knowledge and technology in a wider geographical range and convert them into innovative achievements, which reduces their R&D costs and promotes level of enterprise innovation (Shen Minghao, 2022). On the other hand, the new technology and knowledge developed by enterprises can break the geographical limitation and spread widely in a short time, to provide innovation elements for other enterprises. The value of the enterprise innovation can be realized in the broader market, significantly reducing the marginal cost of enterprise innovation, improving the enterprise innovation enthusiasm and promoting the level of enterprise's innovation (shi-ying hou, etc., 2021). The development of digital economy realizes the effective allocation of resources on the chain of transmission of technology and knowledge and promotes the healthy development of social innovation. Based on the above analysis, Hypothesis 1a and 1b is proposed:

H1a: The development of digital economy can promote enterprises to increase the quantity of innovation.

H1b: The development of digital economy can promote enterprises to improve the quality of innovation.

2.2 Digital economy, human capital level and enterprise innovation

Based on the factor endowment theory, the difference of innovation factorsis the key factor affecting the innovation level of enterprises, and for enterprises, the level of human capital directly affects the innovation level of enterprises (HAYTON, 2005), which cannot be underestimated in promoting the sustainable development of enterprises. By increasing regional human resources and improving the human capital structure of enterprises, the digital economy improves the human capital level of enterprises, then enhances the innovation level of enterprises.

From a macro perspective, cross-border integration of the digital economy and real enterprises can promote the industrial agglomeration of regions, whichbrings together a large number of innovation factors, including research funds, advanced technology and lots of talent resources, etc. At the same

time, the rotation of outstanding talents to work and learn among various enterprises is conducive to the diffusion of new knowledge and technology, and for each talent, they can master a large number of new technologies in a short time, promoting the innovation level of enterprises; Industrial agglomeration can also strengthen collaborative innovation among enterprises. The R&D of new products and services can be divided into multiple parts between enterprises, which increases the possibility of success of enterprise innovation, reduces the R&D costs and stimulates enterprises' innovation enthusiasm (Zhu Xi'an and Zhang Xiu, 2020); The popularity of the Internet and the application of digital technology have broken the regional barriers of the traditional labour market and promoted the innovation factors (especially the talent resources) flow and allocate between regions (Cong Yi and Yu BoYang, 2020). Regions with a high digital economy development level can attract a large number of highly skilled talents from other regions, brings abundant talent resources to local enterprises and enhances their innovation level; In addition, The development of digital economy enables the digital transformation of public services, such as" digital education" and "digital healthcare", which has greatly improved the convenience of life and met the living needs of highly skilled personnels, to attract more highly skilled talents to work for local enterprises and enhance the innovation level of local enterprises.

From a micro perspective, in the digital economy, the popularity of the Internet has broken the time and space barriers of the traditional labour market and alleviated the information asymmetry problem between enterprises and laborer, promoting efficient allocation of labor resources, and the choice of enterprises for workers and the employment choice of the labour have been appropriately matched. (ACEMOGLU and RESTREPO, 2018). With the advancement of digital technology, the digital economy and the real economy are deeply integrated, and data participates in the production process of enterprises as a new production factor, bringing great changes to the production mode of enterprises and promoting the digital transformation of real enterprises. With the digital transformation, the demands of enterprises for high-end labour rises and more high-skilled jobs appear, while the application of digital technology replaces low-skilled labour and enterprises' demand for low-end labour declines, the human capital level is upgraded eventually. With the inflow of high-end talents and high-quality intellectual capital, the quality and quantity of enterprise innovation significantly increases (Jiang Dianchun and Pan Xiaowang, 2022). Meanwhile, the increase of high-skilled labour in digital enterprises promotes innovation of enterprises and drives the development of high-tech industries, which will further increase the demand for high-level labour in enterprises and achieve a virtuous cycle.Based on the above analysis, Hypothesis 2 is proposed:

H2: The development of digital economy increases the quantity of innovation of enterprises and improves quality of innovation of enterprises by upgrading the human capital level of enterprises

2.3 Digital economy, financing constraints and enterprise innovation

Sufficient R&D fund is essential for the orderly implementation of innovation activities. However, innovation is a risky activity with high uncertainty. It is often difficult for non-state-owned enterprises and small-scale enterprises to obtain sufficient innovation funds. Filling the innovation funding gap and alleviating the financing constraint can be crucial to improve the innovation level of enterprises. By expanding channel to external financing and reducing information asymmetries between financial institutions and enterprises, the digital economy can provide more financial support to enterprises' innovation activities,then promotes the quantity and quality of innovation of enterprises.

On the one hand, in digital economy, thanks to the development and application of digital technologies such as big data, block chain and artificial intelligence, digital finance and other new financial models rise rapidly, collecting small funds from retail investors through third-party payment channels to increase the supply of funds in the economic system (Wu Xiaoxu and Ren Baoping, 2022). The Internet platform evaluates the credit limits through the daily transaction flow of enterprises and lends money to enterprises, lowering the financing threshold of enterprises and the cost of applying for loans and enabling enterprises to obtain funds efficiently and conveniently. Digital finance breaks the constraints of traditional financial services that are easily bound by hardware condition such as infrastructure and geographical distance, and also overcomes stock constraints, to improve the

efficiency of the allocation of financial capital in society and expand external financing channels for enterprises.The development of digital economy enables the "long-tail" groups to obtain financial services, and increases the source of enterprises' innovation funds ,then promotes their innovation level.

On the other hand, in the traditional financial, due to the serious information asymmetry between financial institutions and enterprises, financial institutions often discriminate heavily against non-state enterprises and small and medium-sized enterprises in their lending activities and set high lending thresholds and financing costs to hinder enterprises from obtaining funds, which not only leads to an uneven distribution of social financial resources, but also severely limits the enterprises' innovation activities. With the development of digital economy, digital enterprises embed the enterprise data intelligence and network coordination into the capital allocation mechanism, enabling financial institutions to clearly understand the real operation of enterprises and assess their ability to repay debts on time; At the same time, financial institutions use digital technology to build risk assessment models to identify and control lending risk, which not only reduces financial institutions' search costs, processing costs, risk assessment costs and transaction costs (Zou Wei and Ling Jianghuai, 2018), but also reduces the information asymmetry between financial institutions and enterprises.The digital economy avoids the risks of ex ante adverse selection and ex post moral that exist in the traditional financial markets, promoting the effective allocation of social financial resources, alleviating the financing constraints of enterprises, ensuring sufficient financial support for innovation of enterprises and promoting the innovation activities of enterprises. Based on the above analysis, Hypothesis 3 is proposed:

H3: The development of digital economy increases the quantity of innovation of enterprises and improves quality of innovation of enterprises by alleviating financing constraints.

3. Research design

3.1 Research sample and data sources

To test our hypotheses, we use a sample of Chinese A-share listed companies from 2012 to 2020. The original sample is processed as follows: (1) we eliminate financial companies; (2) we eliminate ST-, SST-, and *ST-listed enterprises; (3) we eliminate observations with significant missing data.To avoid the influence of extreme values,we winsorize all continuous variables at the 1% and 99% levels. After the above   processing, a set of unbalanced panel data consisting of 8447 valid observations is obtained. The enterprise-level data involved in this study come from CSMAR, WIND and CNRDS databases, and the provincial-level data come from the official website of the National Bureau of Statistics, the China Statistical Yearbook, the statistical yearbooks of each province and the Peking University Digital Inclusive Finance Index compiled by Guo Feng et al. (2020).

3.2 Baseline model specification

Following the existing literature (Shen MingHao et al.,2022; Peng ShuoYi and Zhang YingYing,2022), we establish the fixed effects model to test the relationship between the development of the digital economy and enterprise innovation:

$$Innov_{m,i,t} = \alpha + \beta DIE_{m,t-1} + \gamma \sum Controls_{i,t-1} + Year + Indus + \varepsilon_{m,i,t-1} \quad (1)$$

$Innov$ represents the level of enterprise innovation; DIE represents the development level of digital economy. $\sum Controls$ represents a set of control variables. $Year$ and $Indus$ respectively represent year fixed effect and industry fixed effect. ε is the random disturbance term. To mitigate endogeneity, all explanatory variables are processed with a one-period lag.

Based on the research of the direct impact of the development of the digital economy on the level of enterprise innovation, this study further examines the mediating effect of human capital level of enterprises and financing constraints by using the mediating effect model.

3.3 Variable selection

(1) Quantity and quality of enterprise innovation

This paper draws on the idea of Cornaggia et al. (2015) to reflect the level of enterprise innovation from two dimensions: the quantity of enterprise innovation and the quality of enterprise innovation, and selects the number of patent applications in a certain year to represent the quantity of enterprise innovation. We add one to the number of patent applications, take the logarithm and include it into the regression equation. The quality of enterprise innovation is represented by excluding the self-citations of all patents from the total citations of all patents which are applied for in a certain year. We add one to the patent citations, take the logarithm and include it into the regression equation.

(2) The digital economy development level

Following the existing literature (Wang Jun et al.,2021; Shen MingHao et al., 2022), this study establishes and measures the indicators of digital economy development level of 30 provinces of China from 2012 to 2020. In this study, three primary indicators are set: digital economy development infrastructure, digital industrialization and digitization of industry. These three primary indicators are subdivided into 9 secondary indicators as follows:traditional infrastructure, new digital infrastructure, Size of the telecommunications industry and level of communications capacity, size of the software industry, scale of IT services, digitization of the primary industry, digitization of the secondary industry and digitization of the tertiary industry. Furthermore, we subdivide the 9 secondary indicators into 18 tertiary indicators, such as the number of Internet broadband access ports, the number of Internet broadband access subscribers, mobile phone exchange capacity, length of fibre optic cable routes with long distance, rural broadband access users, digital Inclusive Finance Index and so on. We adopt the entropy evaluation method to measure the comprehensive index of digital economy development level.

(3) Mediating variables

Human capital level (*Hum*): Drawing on the ideas of Jiang Dianchun and Pan Xiaowang (2022), this paper selects the ratio of the number of employees with a bachelor's degree or above to the total number of employees in a company as a quantitative indicator of human capital level.

Financing constraint (*FC*): Drawing on the ideas of Lu Shengfeng et al. (2017), this study selects SA index, takes its absolute value and takes the logarithm, then includes it into the regression equation.The *SA* index is calculated as follow:

$$SA = -0.737 \times Size + 0.043 \times Size^2 - 0.04 \times Agecom \tag{2}$$

Size represents the logarithm of the total assets of the enterprise at the end of the year and *Agecom* represents the duration of the enterprise.

(4) Control variables

In this study, control variables are selected at both micro and macro levels, the control variables selected at the micro level as follows: enterprise size (*Size*), enterprise age (*Age*), return on assets (*ROA*), fixed assets ratio (*PPE*), intangible assets ratio (*Iar*), equity concentration (*Shr*), enterprise growth (*Growth*); and the control variables selected at the micro level as follows:level of financial development (MAR) and level of industrial structure (STA).

4. Analysis and results

4.1 Descriptive statistics of main variables

Table 1 shows the descriptive statistics of the main variables. It can be seen that the difference between the maximum and minimum values of Quantity and Quality is large, and the standard deviation is large, which indicates that there are obvious differences in the innovation level of different enterprises. The mean value of the quantity of enterprise innovation is smaller than the median, which indicates the there is a significant left-skewed feature and the quantity of innovation of some enterprises is very low; The mean value of quality of enterprise innovation is larger than the median,indicating that there is an obvious right-skewed feature and the quality of innovation of some enterprises is very high; Although the standard deviation of digital economy development level index is small, the difference between the maximum value and the minimum value is large, which indicates that the digital economy development level varies greatly in different regions. The value of digital

economy development level index is decimal, resulting in a small standard deviation, we consider this relativity and found that the difference of digital economy development level index is large, which increases the reliability of the conclusions of this paper. Meanwhile, the mean value of the digital economy development level index is slightly larger than the median, which indicates that the digital economy development level also has right-skewed characteristics and the digital economy development level of some provinces is very high.

Table 1 Descriptive statistics of the main variables

Variable	Mean	P50	Sd	Min	Max
Quantity	2.777	2.944	1.989	0.000	7.776
Quality	2.435	1.946	2.484	0.000	8.746
DEI	0.235	0.224	0.128	0.035	0.578
Size	22.899	22.734	1.421	19.977	27.001
Age	2.990	3.029	0.276	2.048	3.502
ROA	0.037	0.032	0.053	-0.165	0.201
PPE	0.217	0.178	0.174	0.001	0.722
Iar	0.051	0.033	0.067	0.000	0.440
Shr	0.581	0.585	0.163	0.221	0.923
Growth	0.216	0.072	0.808	-0.595	6.380
ECO	11.138	11.166	0.45	10.140	12.009
MAR	3.843	3.390	1.576	1.831	7.875
STA	1.629	1.22	1.104	0.716	5.297

Note: "*", "**" and "***" denote significant at 10%, 5% and 1% significance levels respectively, and the values in brackets are t-values.

4.2 Regression results and analysis

(1) Baseline regression results

This study establishes the fixed effects model for the regressions. Table 2 reports the results of the benchmark regressions which control the year fixed effect and industry fixed effect. Columns (1) and (3) are the regressions of Quantity and Quality of enterprise innovation on the level of digital economy development separately, showing that the level of digital economy development are significantly positive at the 1% significance level in both regression (1) and (3), which indicates that the development of digital economy has a positive impact on both the quantity and quality of innovation of enterprises. Regressions (2) and (4) further include other control variables that affect the quality and the quality of innovation of enterprises. The regression results show that the level of digital economy development is significantly positive at the 1% significance level in both regression (2) and (4), the above findings remain unchanged, indicating that the development of digital economy not only increases the quantity of innovation of enterprises, but also improves the quality of innovation of enterprises. H1a and H1b are verified.

Table 2 The impact of the development of digital economy on the quantity and quality of innovation of enterprises

Variable	(1) Quantity	(2) Quantity	(3) Quality	(4) Quality
L. DEI	2.705***	1.408***	3.415***	3.002***
	(14.260)	(4.080)	(15.340)	(7.140)
L.Size		0.691***		0.717***
		(47.840)		(40.760)
L.Age		-0.896***		-0.876***
		(-12.120)		(-9.730)
L.ROA		2.253***		2.517***
		(5.900)		(5.420)

L.PPE		-1.766***		-2.140***
		(-14.960)		(-14.890)
L. Iar		-1.002***		-1.765***
		(-3.610)		(-5.230)
L. Shr		-1.127***		-1.411***
		(-8.810)		(-9.060)
L.Growth		-0.0760***		-0.103***
		(-3.380)		(-3.760)
L.MAR		-0.0699***		-0.103***
		(-3.550)		(-4.320)
L.STR		-0.389***		-0.0748
		(-3.320)		(-0.520)
Intercept term	2.235***	-9.233***	1.608***	-10.39***
	(47.630)	(-23.320)	(29.220)	(-21.550)
Year	YES	YES	YES	YES
Indus	YES	YES	YES	YES
N	7098	7098	7098	7098
R^2	0.028	0.289	0.032	0.238

Note: "*", "**" and "***" denote significant at 10%, 5% and 1% significance levels respectively, and the values in brackets are t-values.

(2) Robustness test

We conduct several robustness tests as follows:

1) Using the number of patent acquisition in a certain year to measure the quantity of enterprise innovation and the proportion of the number of invention patent application to the number of total patent application to measure the quality of enterprise innovation, and using them as explanatory variables to re-validate the benchmark regression results, the H1a and H1b are still verified, proving the regression results are robust.

2) Since the number of patent citations is always not less than zero, the Tobit regression is used, and the H1a and H1b are still verified, proving the regression results are robust.

3) The fixed effects of the benchmark models are set to a higher order form of the year and industry interaction, while controlling the individual fixed effect,we re-validate the benchmark regression results,and the H1a and H1b are still verified, proving the regression results are robust.

5. Further analysis and mechanism test

According to the theoretical analysis above, the development of the digital economy may improve the level of enterprise innovation by increasing the level of enterprise human capital and alleviating enterprise financing constraints. Drawing on the ideas of Wen Zhonglin and Ye Baojuan (2014), this study establishes the following recursive equations to test the mechanism：

$$Innov_{m,i,t} = \alpha + \beta DIE_{m,t-1} + \gamma \sum Controls_{i,t-1} + Year + Indus + \varepsilon_{m,i,t-1} \qquad (3)$$

$$Medium_{m,i,t-1} = \alpha + \beta DIE_{m,t-1} + \gamma \sum Controls_{i,t-1} + Year + Indus + \varepsilon_{m,i,t-1} \qquad (4)$$

$$Innov_{m,i,t} = \alpha + \beta DIE_{m,t-1} + \theta Medium_{m,i,t-1} + \gamma \sum Controls_{i,t-1} + Year + Indus + \varepsilon_{m,i,t-1} \ (5)$$

Medium is the mediating variable; the other components are explained as above. To mitigate endogeneity, the mediating variables are processed with a one-period lag.

5.1 Human capital Level of enterprises

The development of the digital economy may improve the level of enterprise innovation by increasing the level of enterprise human capital. Table 3 reports the results of the test for the mediating effect of human capital level of enterprise. The regressions (1)-(3) report the results of testing the mediating effect of human capital level between the development of the digital economy and the

quantity of enterprise innovation. regression (1) is the baseline regression; The result of regression (2) shows that the level of digital economy development and the level of enterprise human capital are positively correlated at the 1% significance level, indicating that improving the regional digital economy development level can promote the human capital level of local enterprises; regression (3) founds that the level of digital economy development and the quantity of enterprise innovation are significantly correlated at the 1% significance level, and the regression coefficient decreases compared to regression (1), while the level of enterprise human capital is positively correlated with the quantity of enterprise innovation at the 1% significance level, indicating that the digital economy increases the quantity of enterprise innovation by improving the level of enterprise human capital. Further, regressions (4)-(6) test the mediating effect of human capital level between the level of the digital economy development and the quality of enterprise innovation, and the results are consistent with the quantity of innovation. Thus, H2 is verified.

Table 3 Analysis of mediation mechanism: Human capital Level of enterprises

Variable	(1) Quantity	(2) L. Hum	(3) Quantity	(4) Quality	(5) L. Hum	(6) Quality
L. DEI	1.408***	0.148***	1.244***	3.002***	0.148***	2.752***
	(4.080)	(3.700)	(3.630)	(7.140)	(3.700)	(6.630)
L. Hum			1.107***			1.692***
			(10.870)			(13.710)
Controls	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
Indus	YES	YES	YES	YES	YES	YES
N	7098	7098	7098	7098	7098	7098
R^2	0.289	0.110	0.300	0.238	0.11	0.257

Note: "*", "**" and "***" denote significant at 10%, 5% and 1% significance levels respectively, and the values in Brackets are t-values.

Table 4 Analysis of mediation mechanism: financing constraints

Variable	(1) Quantity	(2) L. FC	(3) Quantity	(4) Quality	(5) L. FC	(6) Quality
L. DEI	1.408***	-0.046***	1.217***	3.002***	-0.046***	2.824***
	(4.080)	(-6.080)	(3.530)	(7.140)	(-6.080)	(6.720)
L. FC			-4.173***			-3.907***
			(-7.690)			(-5.900)
Controls	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
Indus	YES	YES	YES	YES	YES	YES
N	7098	7098	7098	7098	7098	7098
R^2	0.289	0.765	0.295	0.238	0.765	0.241

Note: "*", "**" and "***" denote significant at 10%, 5% and 1% significance levels respectively, and the values in Brackets are t-values.

5.2 Financing constraints

The development of the digital economy may also promote the level of enterprise innovation by alleviating their financing constraints. Table 4 reports the results of tests for the mediating effect of financing constraints.The regressions (1)-(3) report the results of testing the mediating effect of financing constraints between the development of the digital economy and the quantity of enterprise innovation. Regression (1) is the baseline regression; regression (2) tests whether the digital economy has a significant effect on financing constraints. The result of regression shows that the level of digital economy development and financing constraints are negatively correlated at the 1% level of significance, indicating that the level of digital economy development is higher, the financing

constraints on enterprises is smaller; regression (3) founds that the level of digital economy development and the quantity of enterprise innovation are positively correlated at the 1% level of significance, and the regression coefficient declines compared to regression (1), indicating that the digital economy increases the quantity of enterprise innovation by alleviating enterprise financing constraints. Further, regressions (4)-(6) in Table 4 test for the mediating effect of financing constraints between the level of the digital economy development and the quality of innovation, and the results are consistent with the quantity of innovation. Thus, H3 of this paper is validated.

6. Conclusions and recommendations

This paper empirically explores the impact of the development of the digital economy on the level of enterprise innovation. The research results show that the development of digital economy not only promotes enterprises to increase the quantity of innovation, but also promotes enterprises to improve the quality of innovation, indicating that the digital economy has become the main driving force of enterprise innovation in China. Further mechanism analysis shows that the development of digital economy enhances the innovation level of enterprises by improving human capital level of enterprises and alleviating financing constraints. The findings of this paper have important policy implications on how to make full use of the digital economy to promote enterprise innovation and empower China's innovation-driven development strategy and promote high-quality economic development in China. First, local governments should accelerate the construction of the digital economy by increasing the investment in 5G technology, artificial intelligence and other Internet fields and promoting the deep integration of the digital economy with the real economy, to continuously foster new industries, new business models and new modes, and imrove the innovation level of enterprises; Second, for regions with low human capital level, local governments should consider vigorously developing the digital economy to form regional industrial agglomeration,to attract the inflow of innovation factors (especially talent resources), enhance the innovation level of enterprises and the region and promote local economic development eventually.

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