

Firm-level analysis of digital economy advancement

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Abstract. With the development of information technology, China's digital economy has played an increasingly important role in the overall economic structure. However, previous understandings of digital economy advancement have been limited to the national or regional level, with little exploration of how digital economy progress reflects firm-level innovation performance. Therefore, this study aims to address the following questions: Does the development of the digital economy promote corporate innovation? In non-state-owned enterprises, is the positive relationship between digital economy development and corporate innovation performance significant? Addressing these questions can contribute to a better understanding of the relationship between information technology integration and corporate innovation performance. To this end, this study utilizes data from the China Urban Statistical Yearbook (2011–2022), including the total per capita use of telecommunications services in Chinese cities, the proportion of employees engaged in computer services and software, the number of internet users per 100 people, the number of mobile phone users per 100 people, and the China Digital Inclusive Finance Index (jointly compiled by the Peking University Digital Finance Research Center and Ant Group). Using principal component analysis, a digital economy index was constructed for different cities and years. This study systematically examines the impact and mechanisms of digital economy development on corporate innovation, as well as the variations in this impact across different types of listed companies. The findings indicate that the level of digital economy development influences changes in corporate innovation. Specifically, the higher the level of digital economy development, the higher the level of corporate innovation. This research aims to help firms recognize the advantages of digital transformation and the emerging trends in corporate innovation.

Keywords: digital economy development, corporate innovation, information technology, firm characteristics, panel regression

1. Introduction

The digital economy is a series of economic activities that revolve around digitalized information and knowledge as core production factors. By leveraging modern information networks and effectively utilizing information technology, it drives economic structural optimization and productivity growth. With the rapid development and widespread application of information technology, the digital economy has become a crucial force in global economic transformation and growth. In China, the digital economy has gained increasing prominence within the overall economic structure, emerging as a new engine for economic expansion. However, while the impact of the digital economy at the national and regional levels has been extensively studied, its influence on firm-level innovation performance has received little in-depth exploration. Enterprises play a vital role in a nation's socioeconomic framework; they are not only the fundamental units of the national economy but also the primary drivers of economic growth, productivity, and employment. To gain a more comprehensive understanding of the multifaceted impact of the digital economy—particularly its role in fostering corporate innovation—this study seeks to address this research gap.

Corporate innovation is a key factor in driving technological advancement, industrial upgrading, and sustained economic growth. Within the context of the digital economy, the integration and application of information technology have introduced new opportunities and momentum for corporate innovation. However, firms exhibit varying performance in digital transformation and innovation, which may be influenced by factors such as ownership structure, industry characteristics, and resource endowments. Therefore, a thorough investigation into how digital economy development affects corporate innovation and the mechanisms behind this influence is of great significance for helping enterprises seize digital transformation opportunities and enhance innovation performance.

This study aims to address two core questions: first, does the development of the digital economy promote corporate innovation? Second, is the positive relationship between digital economy development and corporate innovation performance

more pronounced in non-state-owned enterprises? Answering these questions will deepen our understanding of the relationship between information technology integration and corporate innovation performance, providing valuable insights for policymakers and corporate managers.

To achieve these research objectives, this study constructs a digital economy index for different cities using principal component analysis, which serves as the explanatory variable to measure the level of digital economy development. Meanwhile, listed companies on the Shanghai and Shenzhen A-share markets are selected as the research sample, with Research and Development (R&D) investment intensity and the proportion of R&D personnel serving as proxy variables for corporate innovation levels. Using panel regression analysis and other empirical methods, this study systematically examines the impact of digital economy development on corporate innovation and explores the variations in this impact across different types of listed companies.

The significance of this study lies in its ability to reveal the role and underlying mechanisms of the digital economy in promoting corporate innovation activities. Furthermore, it provides empirical evidence to help firms recognize the advantages of digital transformation and grasp innovation trends. Additionally, the findings will offer scientific support for policymakers in formulating policies to promote digital economy development and optimize the corporate innovation environment. It is hoped that this study will provide valuable guidance and insights for corporate innovation practices in the digital economy era.

2. Theoretical basis and research hypotheses

Enterprises are a key component of a nation's economic activities and serve as an essential carrier of the digital economy. Innovation theory posits that innovation is a critical driver of economic growth and social progress. As the main entities of innovation, enterprises continuously enhance their competitiveness and market share through the research and development of new technologies, products, and services. Meanwhile, digital economy theory defines the digital economy as a series of economic activities in which digitalized knowledge and information serve as key production factors, modern information networks function as primary carriers, and the effective application of information and communication technology acts as a major driver of efficiency improvement and economic structural optimization. The development of the digital economy facilitates information flow and sharing, reduces transaction costs, and improves resource allocation efficiency, thereby providing strong support for corporate innovation. Against this backdrop, the integration of information technology and innovation within the digital economy presents new development opportunities for enterprises. Hence, this study proposes the following hypothesis:

H1: The development of the digital economy promotes corporate innovation.

On the other hand, the theory of firm heterogeneity suggests that enterprises exhibit differences in resource endowments, organizational structures, and business strategies, which in turn lead to varying responses and innovation capabilities in the face of digital economy development. In particular, non-state-owned enterprises, due to their more flexible operational mechanisms and stronger market adaptability, may be better positioned to leverage their innovation potential in a digital economy environment. Given this context, exploring the impact of digital economy development on corporate innovation and examining its effects within non-state-owned enterprises is of particular importance. Therefore, this study proposes a second hypothesis:

H2: In non-state-owned enterprises, the positive relationship between digital economy development and corporate innovation performance is more pronounced.

3. Empirical tests

3.1. Sample selection and data sources

This study selects annual data from A-share companies listed on the Shanghai, Shenzhen, and Beijing stock exchanges for the period 2011–2022, sourced from the East Money Choice financial database. To ensure the reliability of the research findings, the original sample is screened according to the 2012 industry classification standard issued by the China Securities Regulatory Commission (CSRC) and the following criteria: (1) excluding companies with missing variable data; (2) excluding financial sector companies; and (3) avoiding firms subject to ST or *ST designation during the sample period. After screening, a final dataset of 5,419 sample companies is obtained for analysis.

3.2. Variable definition and measurement

3.2.1. Dependent variable – corporate innovation level (RD)

Corporate innovation, as the dependent variable, is measured using R&D intensity (RD), which reflects the level of investment in innovation. Following the studies of Tang et al. (2009) and Dai & Cheng (2013), RD is calculated as the ratio of R&D expenditure to operating revenue, with a higher RD value indicating a more active level of corporate innovation [1, 2].

3.2.2. Independent variable – Digital economy Development Level (DDI)

The study collects data from the China City Statistical Yearbook (2011–2022) on the total per capita usage of telecommunication services, the proportion of employees engaged in computer services and software, the number of internet users per 100 people, the number of mobile phone users per 100 people, and the China Digital Inclusive Finance Index (jointly compiled by the Peking University Digital Finance Research Center and Ant Financial). Using Principal Component Analysis (PCA), the digital economy index for each city and year is constructed. The specific formula is as follows:

$DDI = PCA \text{ (Total Per Capita Telecommunication Usage + Proportion of Employees in Computer Services and Software + Internet Users per 100 People + Mobile Phone Users per 100 People + Inclusive Finance Index)}$

3.3. Empirical model

To examine the impact of digital economy development on corporate innovation, this study constructs a multiple regression model based on the hypotheses established earlier. The regression equation is as equation (1):

$$RD_{it} = \beta_0 + \beta_1 DDI_{i,t-1} + \gamma * ControlVariables_{i,t-1} + \varepsilon_{it} \quad (1)$$

where RD_{it} represents the corporate innovation level, $DDI_{i,t-1}$ denotes the digital economy index, and $ControlVariables_{i,t-1}$ includes various control variables, such as firm size ($SIZE$), executive shareholding ($MANAGER$), leverage ratio (LEV), net cash flow (CF), fixed asset ratio (FA), firm growth ($Growth$), and return on total assets (ROA). (as shown in Table 1)

Table 1. Definition of model variables

Type	Name	Symbol	Calculation Method
Dependent Variable	Corporate Innovation Level	RD	R&D expenditure as a proportion of operating revenue
Independent Variable	Digital Economy Index	DDI	PCA (Total per capita telecommunication usage + Proportion of employees in computer services and software + Internet users per 100 people + Mobile phone users per 100 people + Inclusive finance index)
Control Variables	Executive Shareholding	$MANAGER$	Proportion of shares held by management
	Cash Flow	CF	Ratio of operating cash flow to total assets at the beginning of the year
	Firm Size	A	Natural logarithm of total assets
	Leverage Ratio	LEV	Ratio of total liabilities to total assets
	Fixed Asset Ratio	FA	Ratio of fixed assets to total assets at the beginning of the year
	Return on Total Assets	ROA	$EBIT * 2 / (\text{Total assets at the beginning} + \text{Total assets at the end})$
	Book-to-Market Ratio	BM	Book value of assets / Market value of assets
	Firm Growth	$Growth$	Year-over-year revenue growth rate
	Firm Age	AGE	Reference date - Company establishment date

4. Research results and analysis

4.1. Descriptive statistics

Descriptive statistical analysis is conducted to summarize the basic characteristics of each variable. The descriptive statistics for the key variables are presented in Table 2. The results indicate the following:

(1) The mean and standard deviation of the corporate innovation measure are 0.0559 and 0.0774, respectively, suggesting significant variation in innovation levels among sample firms.

(2) The mean of the digital economy index is 2.6518, with a standard deviation of 2.1916, indicating substantial instability in the development level of China's digital economy.

(3) The distribution of other variables falls within a reasonable range.

Table 2. Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Median	Max
RD	5,419	0.0559	0.0774	0.0000	0.0414	3.2373
DDI	5,419	2.6518	2.1916	-2.6692	2.4500	7.8028
MANAGER	5,419	16.2981	18.7126	0	7.7926	89.0200
CF	5,419	5.6729	6.8435	-45.4367	5.4306	66.4138
Growth	5,419	17.5489	44.1365	-85.9099	12.4147	1,435.0818
A	5,419	22.3374	1.2402	18.9332	22.1968	27.4758
ROA	5,419	4.4082	8.4846	-93.0921	4.4832	87.9588
LEV	5,419	41.8757	18.2724	0.8359	42.0187	99.0072
FA	5,419	20.0076	13.4657	0.0260	17.8825	80.9706
BM	5,419	0.4325	0.2846	0.0009	0.3663	2.7757
AGE	5,419	21.0925	5.9154	5	21	66

4.2. Correlation analysis

A correlation analysis is conducted to preliminarily assess whether significant correlations exist among the variables. The correlation test results for the key variables are presented in Table 3. The findings indicate the following:

(1) The correlation coefficient between the digital economy index and corporate innovation level is 0.1124, suggesting that the digital economy has a positive impact on corporate innovation to some extent, which is consistent with the hypothesis.

(2) The absolute values of the correlation coefficients between other variables are all below 0.7, indicating no significant collinearity issues, so all variables can be retained.

Table 3. Correlation test results

	ROA	A	LEV	CF	FA	Growth	BM	MANAGER	AGE	DDI	RD
ROA	1.0000										
A	-0.0404	1.0000									
LEV	-0.4065	0.4905	1.0000								
CF	0.4826	0.0892	-0.1870	1.0000							
FA	0.0057	0.0634	0.0179	0.2199	1.0000						
Growth	0.3813	0.0140	0.0064	0.0785	0.0103	1.0000					
BM	-0.3209	0.3304	0.1439	-0.1192	0.0699	-0.2608	1.0000				
MANAGER	0.1905	-0.4281	-0.2486	0.0088	-0.1226	0.0999	-0.2429	1.0000			
AGE	-0.1307	0.2623	0.1171	-0.0124	0.0522	-0.1102	0.2222	-0.3018	1.0000		

DDI	-0.0224	-0.0494	0.0048	-0.0405	-0.1327	0.0228	-0.0961	0.1209	-0.0174	1.0000
RD	0.0671	-0.3283	-0.2932	-0.1466	-0.1466	0.0123	-0.3304	0.2450	-0.1735	0.1124 1.0000

4.3. Panel regression analysis

Based on the research hypotheses, regression tests were conducted separately on the full sample, the State-Owned Enterprise (SOE) sample, and the Non-State-Owned Enterprise (NSOE) sample. The results of these multiple regression analyses are primarily presented in Table 4.

The regression results indicate the following:

(1) Column (a) shows that the coefficient of Digital economy Development Level (DDI) is positive and statistically significant at the 1% level, suggesting that improvements in digital economy development promote corporate innovation activities. As the digital economy expands, firms gain easier access to and can better analyze large volumes of data. This data-driven decision-making capability allows firms to more accurately identify market demands and technological trends, thereby making more targeted R&D investments, facilitating entry into global markets, and continuously innovating to maintain competitiveness.

(2) Column (b) indicates that after incorporating control variables, DDI remains positive and statistically significant at the 1% level, confirming the validity of Hypothesis H1.

Examining the regression results for SOEs and NSOEs, the following observations can be made:

(1) For SOEs, column (a) shows that the coefficient of DDI is not significant in relation to corporate innovation. In contrast, column (a) for NSOEs shows that DDI remains positive and statistically significant at the 1% level.

(2) After adding control variables, column (b) for SOEs shows that DDI remains insignificant, whereas column (b) for NSOEs shows that DDI continues to be positive and significant at the 1% level. These findings indicate that improvements in digital economy development significantly promote innovation activities in non-state-owned enterprises but do not have a substantial impact on state-owned enterprises, thus confirming Hypothesis H2.

Table 4. Regression results for hypothesis testing

	Full Sample		State-Owned Enterprises		Non-State-Owned Enterprises	
	(a)	(b)	(a)	(b)	(a)	(b)
DDI	0.0015***	0.0013***	0.0002	0.0002	0.0019***	0.0016***
ROA		-0.0010***		-7.037e-05		-0.0012***
A		0.0044***		0.0011		0.0055***
LEV		-0.0009***		-0.0005***		-0.0010***
CF		-0.0005***		-0.0002		-0.0006***
FA		-0.0004***		-0.0001		-0.0005***
Growth		0.0001***		-2.413e-05		0.0001***
BM		-0.0297***		-0.0141***		-0.0397***
MANAGER		-3.741e-06		0.0006***		-3.539e-05
AGE		-0.0009***		-0.0009***		-0.0009***
year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
F	16.588	19.442	10.211	10.717	13.377	15.938

R²	0.1868	0.2322	0.3374	0.3836	0.1716	0.2201
N	5419	5419	1222	1222	4197	4197

Note: The values in the table represent regression coefficients. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.4. Robustness test

This study employs the variable substitution method to conduct a robustness test on the model. By replacing key variables and examining the consistency of the results, this approach enhances the validation of the model's robustness, ensuring the rationality and generalizability of the conclusions.

Considering that R&D personnel constitute a crucial part of R&D investment, the proportion of R&D personnel to total employees serves as an indicator of a firm's innovation investment intensity. Therefore, this study uses the proportion of R&D personnel (RW) as a substitute variable for R&D investment intensity (RD).

The regression results of the digital economy index (DDI) and RW are presented in Table 5. The coefficient of DDI is positive and statistically significant at the 10% level, which aligns with the results of Hypothesis 1, confirming the robustness of the model.

Table 5. Regression results of robustness test

	Full Sample	
	(a)	(b)
DDI	0.1837***	0.1130*
ROA		-0.0063
A		0.0192
LEV		-0.0618***
CF		-0.0279
FA		-0.1538***
Growth		0.0066**
BM		-3.9230***
MANAGER		-0.0060
AGE		-0.0586**
year	Yes	Yes
Industry	Yes	Yes
F	51.566	52.850
R ²	0.4166	0.4512
N	5419	5419

Note: The values in the table represent regression coefficients. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5. Conclusion

Based on data from A-share listed companies in Shanghai, Shenzhen, and Beijing from 2011 to 2022, this study measures corporate innovation levels using R&D investment intensity, defined as the proportion of R&D expenditure in operating revenue. It explores the relationship between digital economic development and corporate innovation, leading to the following conclusions:

(1) The development of the digital economy promotes corporate innovation. On the one hand, the widespread application of digital technology has transformed corporate production methods, improving both efficiency and quality. On the other hand, the rise of the digital economy facilitates information flow and resource sharing, reducing the cost of acquiring innovation resources and providing firms with more opportunities and support for innovation. Therefore, in the context of rapid global advancements in information technology, enterprises tend to adopt proactive innovation strategies to seek new profit growth points and enhance their core competitiveness.

(2) The positive correlation between digital economic development and corporate innovation is more pronounced in non-state-owned enterprises. Due to their greater operational flexibility and stronger market adaptability, non-state-owned enterprises (non-SOEs) may exhibit higher innovation performance in response to digital economic development. First, non-SOEs are generally more market-oriented and customer-driven, allowing them to identify market opportunities and innovate more quickly. Second, non-SOEs have greater autonomy and flexibility in resource allocation and decision-making, enabling them to adapt more rapidly to digital economic trends. Moreover, non-SOEs face intense market competition, which compels them to invest more actively in innovative technologies and business models to enhance their competitiveness and expand market share.

Considering China's actual conditions and the findings of this study, the following policy recommendations are proposed:

(1) Adjust policies based on enterprises' development needs by increasing investment in digital infrastructure, strengthening and consolidating the development of the digital economy, and actively promoting corporate innovation and industrial upgrading.

(2) Support the digital transformation of State-Owned Enterprises (SOEs) through policy incentives and assistance, such as special funding programs, tax incentives, and technological support. At the same time, reforming management mechanisms and organizational structures within SOEs can enhance their market responsiveness and flexibility, allowing them to better leverage the opportunities presented by the digital economy, thereby improving innovation capacity and market competitiveness.

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