Digital Economic Development, Enterprise Investment Efficiency and Green Innovation Performance

Jiajun Wu [a], Hongyuan Mu [b]

School of Fan Gongxiu Honors, Beijing University of Technology, Beijing 510000, China.

[a]wj1472580369wjwj@163.com, [b]wj1472580369wjwj@163.com

Abstract. The advent of the digital economy era has profoundly changed the production, operation and management models of enterprises. Based on the panel data of A-share listed companies in the Shanghai and Shenzhen stock markets, this paper deeply assesses the significant impact of the degree of digital economic development in prefecture-level cities on the green innovation performance of local enterprises from the perspective of green innovation performance. The research finds that the development of regional digital economy has significantly improved the green innovation performance of enterprises. This conclusion still exists under a series of robustness tests. Mechanism analysis indicates that the investment efficiency of enterprises has an important mediating effect in the process of promoting the green innovation performance of enterprises through the development of the digital economy: The development of the digital economy mainly improves investment efficiency by alleviating the problem of excessive investment by enterprises, thereby promoting the green innovation performance. The research results of this paper enrich the relevant literature on the impact of the digital economy on the economic activities of micro enterprises, and the conclusion of the article has important practical significance and policy implications.

Keywords: Digital innovation, green innovation, Investment efficiency.

1. Introduction

The 2022 government work report proposed "building a green manufacturing and service system", the report of the 20th National Congress of the Communist Party of China proposed "accelerating the green transformation of the development mode, implementing a comprehensive conservation strategy, and developing green and low-carbon industries", and the white paper "China's Green Development in the New Era" issued by The State Council in January 2023 pointed out "Unswervingly follow the green development path and promote the green development of industry" A series of strategic deployments have further highlighted the long-term significance of green innovation by continuously carrying out the construction of a green manufacturing system and promoting the green transformation of traditional industries. Green innovation is an important factor in promoting the common prosperity of economic growth and ecological protection [1] (Wesley A Magat, 1978), and the enhancement of green innovation can achieve a win-win situation of enterprise competitiveness and environmental protection [2] (Li Qingyuan et al., 2020). Enterprises are not only the micro landing point of the development of the digital economy, but also an important subject in the implementation of China's innovation-driven strategy [3] (Li Jian et al., 2022). At the same time, as an important force coordinating economic development and environmental protection, they shoulder the mission of promoting the dual growth orientation of economic development and environmental protection [4] (Li Wei 'an et al., 2019). The in-depth development of the digital economy has fundamentally changed the mode of economic development [5] (Filippo Bertani et al., 2019), providing important era opportunities for enterprises to achieve independent innovation [6] (Gregory Vial, 2019).

In recent years, the integration and application of modern information networks and information and communication technologies in the digital economy have become an important driving force for economic development that promotes the digitalization of all factors. The optimization and upgrading of digital information infrastructure characterized by cloud-network integration, green and low-carbon development, and security and controllability, as well as the continuous improvement of the

digital transformation service ecosystem driven by market-oriented services and multi-element support, provide more efficient services for enterprises and reduce the institutional costs of their green innovation. The optimal allocation of regional resources in the digital economy is conducive to solving the practical problem of financing difficulties for enterprises' green innovation [7] (Teng Lei et al., 2020). The in-depth development of the digital economy can cultivate green innovation opportunities for enterprises and enhance their green innovation level and efficiency. Under the background of the new era, promoting green innovation of enterprises by relying on the development of the digital economy has become an important issue of The Times. Therefore, in line with the development trend of the digital economy, scientifically exploring the intrinsic connection between the development of the digital economy and the green innovation of enterprises is of great practical significance for China to better build a green manufacturing and service system and accelerate the green transformation of its development mode.

At present, academic research on the impact of the digital economy on innovation can be divided into two aspects: the macro level and the micro level. Macro-level studies such as urban innovation [8] (Jin Huan et al., 2021), urban innovation capacity [9] (Ma Weibiao et al., 2022), urban scientific and technological innovation [10] (Li Xiaodi et al., 2023), and regional innovation capacity [11-13] (Wen Jun et al., 2019; Xiong Li et al., 2020 Yu Boyang, 2022), Regional Innovation Efficiency [14,15] (Bai Junhong et al., 2022; Zhang Hui et al., 2022), Regional innovation output [16] (Hu Yan et al., 2022), Tourism value network Innovation [17] (Jin Zhun, 2022), Strategic Emerging Industry Innovation [18] (Pan Dong, 2022), Industrial Organization Innovation [19] (Yu Donghua et al., 2021), Industrial chain innovation [20] (Yang Xiaoxia et al. In 2022, and others, rich discussions were made from perspectives such as cities, regions, and industries. At the micro level, the existing research mainly focuses on the innovation willingness of enterprises [21] (Du Xingye, 2022), innovation ability [3] (Li Jian et al., 2022), innovation efficiency [22] (Wang Wenpu et al., 2022), and innovation performance [23,24] (Xin Lin et al., 2022; Tang Yaojia et al., 2022, and other enterprise innovation mechanisms and technological innovation [25] (Dong Xiangshu et al., 2022), green innovation (Zhou Xuefeng et al., 2022; Wei Lin et al. (2022) and other types of enterprise innovation were presented. Although the digital economy has been deeply integrated into all fields of China's economic and social development, empirical research exploring the role of digital economy development in enterprises' green innovation is still scarce. Although a small number of studies have investigated the impact of the digital economy and digital transformation on enterprises' continuous green innovation from the perspective of innovation sustainability, or quasi-natural experiments based on the pilot construction of "smart cities" have been conducted to study the mechanism of action between the development of the digital economy and the green innovation of enterprises. However, no research has yet taken the investment efficiency of enterprises as a consideration factor to explore the relationship and mechanism of action between the development of the digital economy and the performance of green innovation. Therefore, based on the intermediary perspective of enterprise investment efficiency, this paper explores the influence mechanism and regional differentiation of the development of the digital economy on the green innovation of enterprises, providing experience and reference for better achieving the "dual carbon" development goals at the micro level, and offering certain inspirations for subsequent theoretical construction and practical application.

Based on the above discussion, this paper uses the panel data of listed companies in China and the regional digital inclusive finance index of Peking University to conduct a detailed study on the impact of regional digital economic development on the green innovation performance of enterprises. The research finds that the development of the digital economy has a significant positive impact on enterprises' green innovation. This conclusion still exists after a series of robustness tests. Further from the perspective of geographical heterogeneity, the promoting effect of digital economic development on the green innovation performance of enterprises is mainly concentrated in the eastern, central and western regions of China. Furthermore, mechanism analysis indicates that the investment efficiency of enterprises has a mediating effect in the process of promoting green innovation performance through the development of the digital economy. The development of the digital

economy mainly improves the investment efficiency of enterprises by alleviating the problem of excessive investment, thereby promoting the improvement of green innovation performance.

Compared with existing studies, the innovation and marginal contribution of this paper are mainly reflected in three aspects: First, this paper explores the impact of digital economic development on the green innovation performance of enterprises, and further considers the regional heterogeneity of this impact, enriching the existing literature discussing the economic consequences of regional digital economic development; Secondly, the article provides an important perspective on the green innovation performance of enterprises from the perspective of regional digital development factors, enriching the existing related research on green innovation and high-quality development. Thirdly, taking enterprise investment efficiency as the mediating variable, clarify its role mechanism in promoting the improvement of green innovation performance through the development of the digital economy, and enrich and improve the research from the perspective of the driving factors of enterprise green innovation.

The subsequent structural arrangement of this article is as follows: The second part is the review and discussion of relevant literature and the proposal of theoretical hypotheses; The third part introduces the data structure and research design of this paper; The fourth part is the basic empirical results; The fifth part further discusses the mechanism; Finally, there is the conclusive review of the full text and the policy implications.

2. Literature Review and Theoretical Hypotheses

The Impact of Digital Economic Development on Green Innovation Performance. The influence mechanisms of digital economic development on green innovation performance mainly include: First, by applying digital technologies, financial institutions can build diversified and specialized application scenarios through data integration and risk identification, which can enhance the efficiency of loan approval and reduce the financing costs of enterprises [26] (Zhang Jiajia, 2022), precisely allocate funds for enterprises' green innovation, and promote enterprises to carry out multi-dimensional green innovation activities. In addition, the broader development and application of digital finance enable financial institutions to establish credit evaluation and risk control systems for enterprises [27] (Lang Xiangxiang et al., 2021), which is conducive to improving the efficiency of fund allocation, reducing the financial expenses of enterprises, further alleviating the financing problems of enterprises, and enhancing the long-term financial stability of enterprises. This will effectively support the green innovation output of enterprises at the long-term level. Secondly, the digital economy, relying on its capabilities in multi-temporal and spatial information dissemination, data creation and sharing formed based on multi-dimensional and composite digital technologies, cultivates more innovation opportunities by influencing market size, knowledge spillover and factor combination, etc. [28] (Zhao Tao et al., 2020). In addition, the construction of digital technology "Internet + Government Services", the popularization of government cloud facilities such as government official accounts, and the advancement of "digital rule of law and smart justice" provide more efficient services for enterprises, promote the optimization and upgrading of the business environment, facilitate enterprises' timely response to changes in market demand, improve the efficiency of resource allocation, and reduce the institutional transaction costs of enterprises' green innovation. Thirdly, the development of the digital economy promotes the flow of information and the opening up of the market, enhances the quality of public services and the level of urban governance, creates fairer employment and entrepreneurship opportunities, attracts high-quality talents to gather, reduces the cost for enterprises to acquire knowledge and information [22] (Wang Wenpu et al., 2022), accelerates the green technological innovation of enterprises, and promotes enterprises to achieve green innovation. The development of the digital economy creates an environment for enterprises to alleviate financing constraints, optimize business support, and gather talent resources. It enhances the green innovation capabilities of enterprises from aspects such as green innovation funds, green innovation resources, and green innovation talents, promoting the

improvement of green innovation efficiency and performance optimization of enterprises. To sum up, this paper proposes the core theoretical hypothesis 1 of the article:

Hypothesis 1: The development of the digital economy can promote the performance of green innovation.

The Impact of Digital Economic Development on the Investment Efficiency of Enterprises.The influence mechanism of the development of the digital economy on the investment efficiency of enterprises is mainly reflected as follows: First, the development of the digital economy has an impact on the competitive and cooperative relationship of the traditional financial market, intensifying the multi-dimensional competitive behavior of the financial market, and has a certain favorable effect on the investment level and investment efficiency of enterprises [29] (Li Zhisheng et al., 2021). Furthermore, the development of digital finance helps enhance the financial stability of enterprises, further alleviating the problem of inefficient investment by enterprises [30] (Tang Song et al., 2020), optimizing resource allocation, and stabilizing and improving the investment level and efficiency of enterprises. Second, the digital finance facilitated and derived from the development of the digital economy has connected the capital cooperation chain between financial institutions and enterprises through diverse resources [31] (Sun Fangcheng et al., 2023). On the one hand, digital finance assesses the multi-dimensional risks of enterprises based on digital technology, and uses technology to empower the screening and identification of data information [32] (Peter Gomber et al., 2018), facilitating the conclusion of investment and financing businesses between enterprises and financial institutions, and enhancing the investment enthusiasm and efficiency of enterprises. On the other hand, digital finance breaks the scope and mode of traditional financial services [33] (Zhang Zhiyuan et al., 2022), expands the coverage of financial services, optimizes the realization mode of financial services, reduces the risk of enterprise investment assessment, alleviates the problem of information asymmetry in the financing process of enterprises, improves the matching and collaborative efficiency between enterprises and financial institutions, and increases the investment funds of enterprises. Improve the investment efficiency of enterprises. Thirdly, the development of the digital economy promotes enterprises to deepen their digital transformation, invest in core software and hardware equipment, high-quality human capital, and iterative innovation in technological research and development that support their digital transformation, and facilitate the transparency of enterprise organizational management processes such as procurement, production, operation, sales, finance, and quality, thereby enhancing the quality of internal control within enterprises [34] (Jiang Hongli et al., 2022). Based on this, the development of the digital economy further empowers the disruptive transformation and innovation of enterprises' business models, forming highly competitive business value and market logic, providing new opportunities for enterprise investment and promoting the improvement of investment efficiency. Therefore, this paper proposes the following theoretical hypothesis 2:

Hypothesis 2: The development of the digital economy can enhance the investment efficiency of enterprises.

The Impact of Enterprise Investment Efficiency on Green Innovation Performance.The influence mechanism of enterprise investment efficiency on green innovation performance mainly lies in two aspects. First, the improvement of enterprise investment efficiency helps to support green innovation at the strategic level. Through efficient investment behaviors, enterprises have a profound understanding of industry-related in-depth operation and management experiences such as the current situation and development frontiers of the industry, the direction of core technology iteration, business model transformation and market prospects [35] (Wu You et al., 2022), laying a solid industry management foundation and providing strategic guidance for enterprises to carry out green innovation. Second, the relevant channels and cooperative networks nurtured during the long-term investment process of enterprises provide excellent resource support for achieving green innovation. The higher investment efficiency of enterprises can transform the capital base, knowledge base, talent base, technological base, etc. accumulated through information sharing and trust cooperation in the early stage into a powerful driving force for promoting green innovation, build a relatively stable

multi-dimensional investment system for green innovation, and promote the improvement of green innovation performance. Based on this, this paper holds that the investment efficiency of enterprises can enhance the performance of green innovation. Based on the previous analysis of the development of the digital economy, the efficiency of enterprise investment and the performance of green innovation, this paper holds that the development of the digital economy will enhance the efficiency of enterprise investment, and the improvement of enterprise investment efficiency will promote the enhancement of green innovation performance. Therefore, enterprise investment efficiency plays a mediating role between the development of the digital economy and the performance of green innovation. Therefore, this paper proposes the following theoretical hypothesis 3:

Hypothesis 3: The efficiency of enterprise investment is an important mechanism by which the development of the digital economy affects the performance of green innovation.

3. Data Description and Empirical Design

Sample Selection and Data Sources. This paper adopts the panels of all A-share listed companies in the Shanghai and Shenzhen stock markets from 2011 to 2019 as the original samples. The sample data of the original listed companies are all from the CSMAR database of Guotai 'an and have been merged and processed. The green patent data of listed companies is sourced from the National Patent and Intellectual Property Administration. The further screening process of the samples is as follows: Firstly, in order to prevent the abnormal financial indicators of the financial industry from interfering with the empirical results of the article, this paper screens according to the industry codes of the China Securities Regulatory Commission in 2012 and excludes the financial industry. Secondly, in order to obtain more accurate enterprise financial data and avoid the interference of various indicators due to poor enterprise operation, the samples of ST-like companies during the research period were excluded. Thirdly, in order to eliminate the influence of extreme values on the empirical analysis, this paper performs winsorize processing of up and down 1% for all continuous variables. Finally, after deleting the enterprise samples with missing variables, a total of 24,248 observations from 2,606 enterprises were obtained.

Regional Digital Economic Development Indicators. In terms of core explanatory variables, this paper adopts the "Peking University Digital Inclusive Finance Index" released by the research group of the Digital Finance Research Center of Peking University to reflect the development level of the digital economy in each city and matches it with the registered locations of listed enterprises. This index focuses on measuring the development of the digital economy from the perspective of innovative digital finance, and depicts the development level of the digital economy in different regions of China around dimensions such as the digital economy, the breadth of financial coverage, the depth of usage, and the degree of digitalization. Index construction is scientific, rigorous and objective, and has been widely used in related fields.

Enterprise Green Innovation Measurement. This paper uses the natural logarithm lnGPall of the sum of the number of green invention patents authorized and the number of green utility model patents authorized by listed companies in the current year to measure the output of innovation activities in the green environment of listed companies. In the subsequent robustness analysis, green invention patents and green utility model patents will be discussed separately.

Empirical Model Setting. To verify the theoretical hypotheses proposed earlier, this paper intends to construct a bidirectional fixed-effect model to discuss the impact of digital economic development in the location of listed companies on green innovation. The specific empirical analysis model is shown in Equation (1):

$$Green_{it+1} = \beta_0 + \beta_1 Digit_{it} + \beta_2 X_{it} + Year_{FE} + Industry_{FE} + \varepsilon_{it} \quad (1)$$

Among them, the subscripts i and t represent the enterprise and the year respectively. The explained variable $Green_{it+1}$ is the natural logarithm of the sum of the number of authorized green invention patents and green utility model patents of listed company i in the t+1 year, which

comprehensively measures the level of green innovation output of listed companies. The core explanatory variable $Digit_{it}$ is the digital economy level of the city where listed company i is registered. The larger this value is, the higher the digital economy development level of this city is. Therefore, β_1 is the core parameter to be estimated in this paper, and it is expected by theoretical assumptions that β_1 is significantly positive. The five sets of control variables at the enterprise level in the model are specifically set as follows. In order to control the impact of the macro external environment, this paper controls the year fixed effect $Year_{FE}$. Considering the interference of potential and ever-changing factors of the enterprise industry on the causal inference in this paper, Equation (1) also controls for the fixed effect of the enterprise industry $Industry_{FE}$. ε_{it} is the random disturbance term of the model. Finally, in order to prevent the heteroscedasticity problem from affecting the reliability of the empirical results of this paper, all statistical inferences in this paper are discussed based on heteroscedasticity robust standard errors.

Selection and Setting of Control Variables. Referring to the standard practices in the existing literature, the selection of control variables in this paper specifically includes: (1) Enterprise Size, which is measured by the natural logarithm of the total assets of the listed company at the end of the current year; (2) The enterprise's asset-liability ratio (Leverage) is characterized by the proportion of a listed company's total liabilities to total assets in the current year. (3) The Age of the enterprise's listing is measured by the number of years the company has been listed. (4) The operating performance ROA of an enterprise is measured by the return on assets of the listed company in the current year; (5) Fixed asset scale (Fix) is measured by the proportion of fixed assets of the listed company in the current year; (6) Cash ratio (Cash), measured by the ratio of cash held by a listed company in the current year; (7) Board Independence (Indratio), measured by the proportion of independent directors of the listed company in the current year; (8) Boardsize, measured by the proportion of shares held by the board of directors of the listed company in the current year; (9) Top1 in equity concentration, measured by the shareholding ratio of the largest shareholder of the listed company in the current year; (10) SOE of enterprise ownership, a dummy variable, takes 1 if the listed company is a state-owned enterprise; otherwise, it takes 0. The detailed types, names and detailed definitions of each variable are shown in Table 1. The descriptive statistics are shown in Table 2.

Table 1 Types, Names and Detailed Definitions of Each Variable

Types of Variables	Variable Name and Letter Representation	Variable Definition Description
Explained Variable	Green Innovation, *Green_all*	The natural logarithm of the sum of the number of green invention patents and the number of green utility model patents authorized by a listed company in the current year
Core explanatory variable	Economic Development, *Digital*	The total index of digital economic development of the city where the listed company is registered
Enterprise Control Variables	enterprise scale, *Size*	ln (Total Assets of a listed Company at the end of the current Year)
	Enterprise Asset-liability Ratio, *Leverage*	The proportion of total liabilities to total assets of a listed company in the current year
	Enterprise Age, *Age*	The years of listing of a listed company
	Enterprise Operating Performance, *ROA*	The return on assets of listed companies in the current year
	Scale of Fixed Assets, *Fix*	The proportion of fixed assets to total assets of a listed company in the current year
	Cash Ratio, *Cash*	The cash holding ratio of a listed company in the current year
	Board Independence, Indratio	The proportion of independent directors of listed companies in the current year
	Shareholding Ratio of the Board of Directors, *Boardsize*	The shareholding ratio of the board of directors of listed companies

Table 1 Types, Names and Detailed Definitions of Each Variable

Types of Variables	Variable Name and Letter Representation	Variable Definition Description
Enterprise Control Variables	Ownership Concentration, *Top1*	The shareholding ratio of the largest shareholder of a listed company in the current year
	Corporate Ownership, *SOE*	Whether a listed company belongs to a state-owned enterprise

Table 2 Descriptive statistics of variables

	Sample Size	Average	Standard Deviation	Minimum Value	Median	Maximum Value
Green all	24248	0.319	0.735	0	0	6.771
Digit	24248	2.06	0.679	0.213	2.193	3.216
Size	24248	22.111	1.293	19.552	21.927	26.395
Leverage	24248	0.416	0.209	0.032	0.405	0.936
Age	24248	9.584	7.346	0	8	27
ROA	24248	0.447	0.450	-0.581	0.374	2.696
Fix	24248	0.21	0.160	0.002	0.176	0.716
Cash	24248	1.205	2.007	0.046	0.574	24.524
Indratio	24248	38.613	10.559	0	37.5	66.667
Boardsize	24248	11.684	18.963	0	0.158	68.606
Top1	24248	0.348	0.149	0.082	0.328	0.758
SOE	24248	0.335	0.472	0	0	1

Correlation Coefficient Test. Finally, before conducting the empirical regression analysis, a correlation analysis of the main research variables is also required. The results of the correlation test of the control variables are shown in Table 3. It can be known from Table 3 that the correlation coefficients between the core explanatory variables and each control variable are not large. It can be seen from the first column that the correlation coefficients of all control variables and the core explanatory variable Digit do not exceed 0.5. Therefore, the model setting in this paper neither has a systematic bias in the statistical inference of this paper caused by the highly collinear problem, nor does it affect the standard error estimation of the core explanatory variable.

Table 3 Correlation Coefficient Matrix among Variables

	Digit	Size	Leverage	Age	ROA	Fix	Cash	Indratio	Boardsize	Top1	SOE
Digit	1										
Size	0.12*	1									
Leverage	-0.01*	0.53*	1								
Age	0.08*	0.39*	0.38*	1							
ROA	-0.41*	-0.01	0.09*	-0.02*	1						
Fix	-0.13*	0.11*	0.09*	0.09*	0.06*	1					
Cash	0.13*	-0.29*	-0.53*	-0.24*	-0.07*	-0.17*	1				
Indratio	-0.30*	-0.06*	-0.03*	-0.07*	0.18*	-0.00	0.06*	1			
Boardsize	-0.05*	-0.33*	-0.32*	-0.51*	0.02*	-0.15*	0.22*	0.06*	1		
Top1	-0.07*	0.20*	0.05*	-0.06*	0.10*	0.08*	0.00	0.05*	-0.07*	1	
SOE	-0.11*	0.38*	0.30*	0.46*	0.10*	0.20*	-0.15*	-0.03*	-0.42*	0.23*	1

4. Basic Empirical Results

Benchmark Result. The benchmark regression results of the empirical model equation (1) in the previous text are shown in Table 4. Table 4 presents the stepwise regression results of the empirical model in this paper to ensure the robustness of the results for any control variable. The explained variables are all the natural logarithm values of the green patent authorization volume of the listed company in the next year. Among them, column (1) does not control any fixed effects and control variables, and is the result of a univariate OLS estimation; Column (2) adds the year fixed effect and industry fixed effect, and Column (3) further incorporates the control variables at the enterprise level. It can be seen that regardless of the control conditions, the estimation coefficients of all the core explanatory variables Digit of the models are significantly positive at the 1% statistical level, that is, the digital economy has a significant positive impact on the green innovation of enterprises.

Table 4 Digital Economic Development and Green Innovation Performance

Explained Variable	**(1) F.Green_all**	**(2) F.Green_all**	**(3) F.Green_all**
Digit	0.067***	0.384***	0.331***
	(0.008)	(0.028)	(0.027)
Size			0.184***
			(0.007)
Leverage			0.124***
			(0.032)
Age			-0.016***
			(0.001)
ROA			0.032**
			(0.013)
Fix			-0.200***
			(0.038)
Cash			-0.004**
			(0.002)
Indratio			0.001**
			(0.001)
Boardsize			-0.000
			(0.000)
Top1			-0.160***
			(0.037)
SOE			0.037***
			(0.013)
Constant	0.204***	-0.408***	-4.247***
	(0.015)	(0.053)	(0.165)
Year Fixed Effect	Not Controlled	Controlled	Controlled
Industry Fixed Effect	Not Controlled	Controlled	Controlled

Note: The observed values are at the enterprise level. ***, ** and * respectively indicate significance at the statistical levels of 1%, 5% and 10%. The values in parentheses are heteroscedasticity robust standard errors. "Controlled" indicates that the fixed effect has been controlled, and "Not Controlled" indicates that the fixed effect has not been controlled.

Robustness Test. After drawing the benchmark conclusion, in order to verify the robustness of the core results of this paper, multiple robustness tests are still needed for detailed verification.

First of all, green patents are divided into green invention patents and green utility model patents. Generally speaking, the former is more innovative than the latter. To ensure the robustness of the results, this part discusses the two separately to test the robustness of the conclusion of this paper. As shown in Table 5: Among them, the explained variable in column (1), F.Green_fm, is the natural logarithm of the number of green invention patents authorized by the listed company in the next year plus 1; Column (2) The explained variable F.Green_other is the natural logarithm of the number of green utility model patent authorizations in the following year of the listing formula plus 1. Both core explanatory variables, Digit, are significantly positive at the 1% statistical level. Therefore, the conclusion of this paper is robust.

Table 5 Digital Economic Development and Various Green Innovations

Explained Variable	**(1) F.Green_fm**	**(2) F.Green_other**
Digit	0.194***	0.244***
	(0.019)	(0.023)
Size	0.117***	0.141***
	(0.005)	(0.006)
Leverage	0.003	0.134***
	(0.021)	(0.028)
Age	-0.007***	-0.013***
	(0.001)	(0.001)
ROA	0.023**	0.024**
	(0.010)	(0.011)
Fix	-0.142***	-0.139***
	(0.025)	(0.033)
Cash	-0.001	-0.003*
	(0.001)	(0.002)
Indratio	0.001**	0.001*
	(0.000)	(0.000)
Boardsize	-0.000	-0.000
	(0.000)	(0.000)
Top1	-0.109***	-0.094***
	(0.026)	(0.032)
SOE	0.029***	0.019*
	(0.008)	(0.011)
Constant	-2.735***	-3.253***
	(0.130)	(0.144)
Year Fixed Effect	Controlled	Controlled
Industry Fixed Effect	Controlled	Controlled
Observations	20,505	20,505
R-squared	0.109	0.127

Note: The observed values are at the enterprise level. ***, ** and * respectively indicate significance at the statistical levels of 1%, 5% and 10%. The values in parentheses are heteroscedasticity robust standard errors. "Controlled" indicates that the fixed effect has been controlled, and "Not Controlled" indicates that the fixed effect has not been controlled.

Invention authorization quotas: lnGP1, energy conservation invention authorization quota: lnGP2, waste management invention authorization quota: lnGP3, administrative supervision design invention authorization quota: lnGP4, and nuclear power generation invention authorization quota: lnGP5. Different dimensions of green patent estimate results as shown in table 6. It can be seen that the higher the level of digital economy development, the more significantly the number of authorized inventions for alternative energy (Column (1)), energy conservation (Column (2)), and administrative supervision design (Column (4)) of enterprises has been increased.

Table 6 Distinguish the Dimensions of Green Patent Technologies

Explained Variable	(1) F.lnGP1	(2) F.lnGP2	(3) F.lnGP3	(4) F.lnGP4	(5) F.lnGP5
Digit	0.068***	0.137***	0.016	0.041***	0.001
	(0.010)	(0.012)	(0.011)	(0.005)	(0.001)
Size	0.043***	0.056***	0.044***	0.014***	0.000
	(0.003)	(0.004)	(0.003)	(0.001)	(0.000)
Leverage	-0.032***	-0.003	-0.005	-0.018***	0.001
	(0.012)	(0.013)	(0.012)	(0.006)	(0.001)
Age	-0.002***	-0.003***	-0.003***	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ROA	0.018**	-0.004	0.029***	0.003	-0.000**
	(0.007)	(0.004)	(0.007)	(0.002)	(0.000)
Fix	0.040***	-0.135***	0.039***	-0.048***	-0.001
	(0.014)	(0.017)	(0.014)	(0.007)	(0.001)
Cash	-0.000	-0.000	0.001**	-0.001***	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
Indratio	0.000**	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Boardsize	0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Top1	0.005	-0.076***	-0.019	-0.011	-0.002*
	(0.014)	(0.019)	(0.013)	(0.008)	(0.001)
SOE	-0.002	0.008	0.015***	0.010***	0.001**
	(0.004)	(0.006)	(0.004)	(0.003)	(0.000)
Constant	-1.036***	-1.358***	-0.951***	-0.360***	-0.005
	(0.087)	(0.086)	(0.079)	(0.037)	(0.003)
Year Fixed Effect	Controlled	Controlled	Controlled	Controlled	Controlled
Industry Fixed Effect	Controlled	Controlled	Controlled	Controlled	Controlled
Observations	20,505	20,505	20,505	20,505	20,505
R-squared	0.058	0.059	0.081	0.040	0.002

Note: The observed values are at the enterprise level. ***, ** and * respectively indicate significance at the statistical levels of 1%, 5% and 10%. The values in parentheses are heteroscedasticity robust standard errors. "Controlled" indicates that the fixed effect has been controlled, and "Not Controlled" indicates that the fixed effect has not been controlled.

PSM Estimation. This paper further adopts PSM for estimation because there may be systematic differences in the scale of regional digital economic development itself. Propensity score matching (PSM) plays an important role in reducing the correlation between processing variables and observable variables. Therefore, it is proposed to make the causal inference in this paper more accurate through the PSM approach. When PSM matching is carried out, Logit regression is performed on the control variables using the Treat variable to obtain the propensity score value. The individuals in the control group with the closest propensity score values are the paired samples of the experimental group. Through this method, the systematic differences existing between the individuals in the experimental group and the control group can be minimized to the greatest extent, thereby reducing the estimation bias. Therefore, before estimation, a balance hypothesis test of covariates is also required, that is, whether each variable becomes balanced between the experimental group and the control group after matching, that is to say, whether the means of covariates between the experimental group and the control group have significant differences after matching. If there is no significant difference, further model estimation is supported.

Within the empirical analysis framework of this paper, the samples are divided into two groups based on whether the development of the digital economy is higher than the sample mean: The Treatment Group consists of listed companies with a high level of digital economy development, and the Control Group consists of listed companies with a low level of digital economy development. Figure 1 shows the differences in covariates between the treatment group and the control group. It can be seen that the differences between the two types of enterprises have been significantly reduced after matching, meeting the balance assumption conditions.

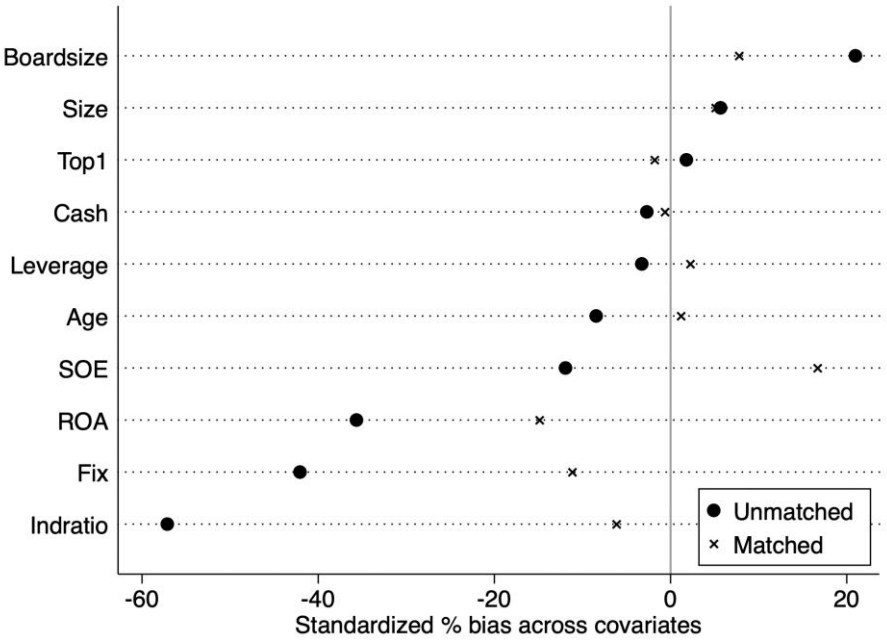

Fig. 1 Match the Differences in Covariates between the Treatment Group and the Control Group Before and After

The PSM estimation results are shown in Table 7. Among them, the explained variable in column (1) is FGreen_all, the explained variable in column (2) is FGreen_fm, and the explained variable in column (3) is FGreen_other. All columns control for bidirectional fixed effects and the control variables mentioned earlier. The core explanatory variables are still significantly positive, which is in line with the basic conclusion in the previous text. Therefore, after estimation using PSM, the conclusion still exists.

Table 7 PSM Estimation Result

Explained Variable	**(1) FGreen_all**	**(2) FGreen_fm**	**(3) FGreen_other**
Digit	0.132***	0.063***	0.100***
	(0.032)	(0.021)	(0.025)
Size	0.190***	0.129***	0.135***
	(0.018)	(0.014)	(0.014)
Leverage	0.142	0.011	0.176**
	(0.094)	(0.062)	(0.073)
Age	-0.017***	-0.008***	-0.013***
	(0.003)	(0.002)	(0.002)
ROA	0.065*	0.039	0.056*
	(0.036)	(0.025)	(0.030)
Fix	-0.127	-0.168**	-0.041
	(0.114)	(0.074)	(0.089)
Cash	0.007	0.011	0.005

Table 7 PSM Estimation Result

Cash	(0.014)	(0.010)	(0.010)
Indratio	0.004**	0.002**	0.003**
	(0.001)	(0.001)	(0.001)
Boardsize	-0.001	-0.000	-0.001
	(0.001)	(0.000)	(0.001)
Top1	-0.247**	-0.186***	-0.114
	(0.112)	(0.069)	(0.090)
SOE	0.052*	0.057***	0.022
	(0.029)	(0.019)	(0.024)
Constant	-3.934***	-2.684***	-2.839***
	(0.365)	(0.279)	(0.284)
Year Fixed Effect	Controlled	Controlled	Controlled
Industry Fixed Effect	Controlled	Controlled	Controlled
Observations	10,657	10,655	10,655
R-squared	0.154	0.117	0.127

Note: The observed values are at the enterprise level. ***, ** and * respectively indicate significance at the statistical levels of 1%, 5% and 10%. The values in parentheses are heteroscedasticity robust standard errors. "Controlled" indicates that the fixed effect has been controlled, and "Not Controlled" indicates that the fixed effect has not been controlled.

Heterogeneity Discussion. Further consider the heterogeneity of the impact of digital economic development on the green innovation performance of micro enterprises. China has a vast territory, numerous administrative divisions and uneven distribution of resources, which leads to significant differences in the economic development levels among various regions. There are notable differences in economy, environment, institutional policies and industrial agglomeration phenomena among different regions. Therefore, this paper conducts a heterogeneity analysis. Table 8 reports in detail the estimation results of regional heterogeneity. Among them, the sub-samples of columns (1), (2), (3) and (4) are listed enterprises whose registered locations are in the eastern region, the central region, the western region and the northeastern region respectively. It can be seen that the estimated coefficient of the core explanatory variable Digit is significantly positive only in the first three columns. Therefore, the promoting effect of digital economic development on the green innovation performance of micro enterprises is mainly concentrated in the eastern, central and western regions.

Table 8 Discussion on Regional Heterogeneity

Explained Variable	(1) F.Green_all	(2) F.Green_all	(3) F.Green_all	(4) F.Green_all
	East	Midland	West	Northeast
Digit	0.355***	0.441***	0.187***	-0.106
	(0.042)	(0.078)	(0.064)	(0.129)
Size	0.183***	0.214***	0.154***	0.146***
	(0.009)	(0.015)	(0.014)	(0.023)
Leverage	0.076*	0.512***	0.203***	-0.336***
	(0.042)	(0.088)	(0.068)	(0.111)
Age	-0.014***	-0.014***	-0.027***	-0.003
	(0.001)	(0.003)	(0.002)	(0.004)
ROA	0.019	0.030	0.127***	-0.056**
	(0.017)	(0.032)	(0.034)	(0.027)
Fix	-0.114**	-0.733***	-0.073	-0.077
	(0.053)	(0.107)	(0.069)	(0.114)

Table 8 Discussion on Regional Heterogeneity

Cash	-0.005**	0.009	0.006	-0.012
	(0.002)	(0.007)	(0.006)	(0.008)
Indratio	0.000	0.003*	0.002*	0.002
	(0.001)	(0.001)	(0.001)	(0.002)
Boardsize	0.000	0.000	-0.003***	0.001
	(0.000)	(0.001)	(0.001)	(0.001)
Top1	-0.186***	-0.034	-0.220***	0.368**
	(0.049)	(0.101)	(0.079)	(0.145)
SOE	0.029*	0.083**	0.052*	0.099***
	(0.017)	(0.036)	(0.028)	(0.032)
Constant	-4.247***	-5.199***	-3.344***	-2.918***
	(0.222)	(0.371)	(0.309)	(0.582)
Year Fixed Effect	Controlled	Controlled	Controlled	Controlled
Industry Fixed Effect	Controlled	Controlled	Controlled	Controlled
Observations	13,943	2,824	2,758	980
R-squared	0.154	0.196	0.180	0.160

Note: The observed values are at the enterprise level. ***, ** and * respectively indicate significance at the statistical levels of 1%, 5% and 10%. The values in parentheses are heteroscedasticity robust standard errors. "Controlled" indicates that the fixed effect has been controlled, and "Not Controlled" indicates that the fixed effect has not been controlled.

5. Conclusion and Policy Implications

Based on the panel data of A-share listed companies in Shanghai and Shenzhen stock markets from 2011 to 2019 and matched with the digital inclusive finance index of the registered locations of listed enterprises, this paper empirically examines the impact of regional digital economic development on the green innovation performance of enterprises, and analyzes the important role played by enterprise investment efficiency in it. The research findings are as follows: First, the development of the digital economy has a significant positive impact on the green innovation of enterprises. Moreover, from the perspective of geographical heterogeneity, the promoting effect on the green innovation performance of enterprises is mainly concentrated in the eastern, central and western regions of China. Second, the efficiency of enterprise investment has a mediating effect in the process of promoting green innovation performance through the development of the digital economy. The development of the digital economy mainly improves the efficiency of enterprise investment by alleviating the problem of excessive investment, thereby promoting the improvement of green innovation performance.

The research in this paper further enriches the relevant literature on the impact of digital economic development on micro enterprises. On this basis, this paper obtains the following inspirations and policy suggestions:

First, the development of the digital economy has significantly driven green innovation among enterprises. Therefore, it is necessary to continue to strengthen the construction of regional digital infrastructure, give full play to its fundamental role in the green economy and high-quality economic development, further promote the digital transformation of industries, accelerate the process of digital industrialization, and cultivate strong momentum and potential for digital development. Promote the in-depth integration of emerging digital technologies and enterprises' green innovation activities, provide support for the flow of innovation elements to enterprises, and fully stimulate the era dividends of the digital economy for enterprises' green innovation. In addition, it is necessary to actively guide the aggregation and synergy of multiple elements such as technology, capital, talent and data, build a digital service ecosystem, and further drive the efficient and green innovation of enterprises.

Second, promote the digital transformation process of enterprises and actively build a green innovation ecosystem. Enterprises should seize the opportunity window of green innovation under the background of the digital economy, increase investment in digital technology research and development, and based on the green innovation mechanism such as innovation cost, innovation efficiency and innovation strategy, utilize digital technology to aggregate the internal green innovation elements of the enterprise, give full play to the positive spillover effect of digital technology innovation, accelerate the digital transformation process of the enterprise, and build an enterprise green innovation ecosystem. In addition, enterprises should fully attach importance to the talent aggregation effect stimulated by the digital economy, build a supporting system for talent introduction, promote the improvement of talent incentive mechanisms, establish a platform for knowledge sharing and co-creation within enterprises, accelerate the flow of green innovation elements within enterprises, stimulate the green innovation vitality of enterprises, and ensure the realization of sustainable and long-term green innovation.

Third, establish and improve the investment management mechanism, build a risk assessment and early warning system, connect the capital cooperation chain between financial institutions and enterprises with diverse resources, aggregate high-quality social resources from multiple dimensions, increase the investment funds of enterprises, promote the rational allocation of investment factors, improve the internal structure of investment governance, and enhance the investment efficiency of enterprises. Based on this, strategic guidance is provided for enterprises' green innovation through the operation and management mechanisms derived from higher investment efficiency, and the information sharing and value co-creation of enterprises' green innovation are accelerated by relying on the enterprise investment cooperation network and channel channels, so as to improve the level of enterprises' green innovation and enhance their green innovation performance.

References

[1] MAGAT W A. Pollution control and technological advance: A dynamic model of the firm [J/OL]. Journal of Environmental Economics and Management, 1978, 5(1): 1-25. https://doi.org/10.1016/0095-0696(78)90002-5

[2] LI Q Y, XIAO Z H. Heterogeneous environmental regulation tools and corporate green innovation incentives—Evidence from green patents of listed enterprises [J]. Economic Research, 2020, 55(9): 192-208.

[3] LI J, ZHANG J L, DONG X F. How does the digital economy affect corporate innovation ability: Internal mechanisms and empirical evidence [J/OL]. Economic Management, 2022, 44(8): 5-22. https://doi.org/10.19616/j.cnki.bmj.2022.08.001

[4] LI W A, ZHANG Y W, ZHENG M N, et al. A study on the green governance and evaluation of Chinese listed companies [J/OL]. Management World, 2019, 35(5): 126-133+160. https://doi.org/10.19744/j.cnki.11-1235/f.2019.0070

[5] BERTANI F, PONTA L, RABERTO M, et al. The complexity of the intangible digital economy: An agent-based model [J/OL]. Journal of Business Research, 2021, 129: 527-540. https://doi.org/10.1016/j.jbusres.2020.03.041

[6] VIAL G. Understanding digital transformation: A review and a research agenda [J/OL]. The Journal of Strategic Information Systems, 2019, 28(2): 118-144. https://doi.org/10.1016/j.jsis.2019.01.003

[7] TENG L, MA D G. Can digital finance promote high-quality development? [J/OL]. Statistical Research, 2020, 37(11): 80-92. https://doi.org/10.19343/j.cnki.11-1302/c.2020.11.007

[8] JIN H, YU L H. Digital economy, urban innovation and regional convergence [J/OL]. Southern Economy, 2021(12): 21-36. https://doi.org/10.19592/j.cnki.scje.390885

[9] MA W B, WU Y M. The impact of digital economic development on the innovation ability of Chinese cities [J]. Economic System Reform, 2022(6): 43-51.

[10] LI X D, RAO M X. A study on the configurational path of digital economy enabling urban technological innovation [J/OL]. Scientia Sinica Studia, 2023: 1-20. https://doi.org/10.16192/j.cnki.1003-2053.20230113.002

[11] WEN J, YAN Z J, CHENG Y. Digital economy and the enhancement of regional innovation ability [J]. Economic Research Journal, 2019(11): 112-124.

[12] XIONG L, CAI X L. The impact effect of digital economy on the enhancement of regional innovation ability—An empirical study based on the Yangtze River Delta urban agglomeration [J/OL]. East China Economic Management, 2020, 34(12): 1-8. https://doi.org/10.19629/j.cnki.34-1014/f.200924016

[13] YU B Y. Digital economy, factor market-oriented allocation and regional innovation ability [J]. Economics and Management, 2022, 36(2): 36-42.

[14] BAI J H, CHEN X. Digital economy, spatial spillover effect and regional innovation efficiency [J/OL]. Research and Development Management, 2022, 34(6): 67-78. https://doi.org/10.13581/j.cnki.rdm.20211722

[15] ZHANG H, YI J B, XU J X. A study on the spatial spillover effect of digital economy on regional innovation efficiency—From the perspective of factor market-oriented allocation [J]. Securities Market Tribune, 2022(7): 13-22.

[16] HU Y, DAI J J, ZHANG A W. Digital economy, spatial association and regional innovation output—With a discussion on the threshold effect of regional absorption capacity [J]. Science and Technology Management Research, 2022, 42(15): 79-88.

[17] JIN Z. Digital economy and innovation of tourism value network [J/OL]. Tourism Tribune, 2022, 37(10): 5-6. https://doi.org/10.19765/j.cnki.1002-5006.2022.10.003

[18] PAN D. A study on the innovation and development of strategic emerging industries empowered by digital economy [J/OL]. Theoretical Discussion, 2022(5): 168-172. https://doi.org/10.16354/j.cnki.23-1013/d.2022.05.022

[19] YU D H, LI Y H. Industrial organization innovation in the digital economy era—Taking the digital technology-driven industrial chain cluster ecosystem as an example [J]. Reform, 2021(7): 24-43.

[20] YANG X X, CHEN X D. Can the digital economy promote industrial chain innovation?—Empirical evidence based on the OECD input-output table [J]. Reform, 2022(11): 54-69.

[21] DU X Y. Digital economy market structure evolution and corporate innovation willingness—A two-stage DEA-Tobit test based on internet platform enterprises [J]. Learning and Exploration, 2022(9): 118-126.

[22] WANG W P, XU A T. Can the digital economy drive corporate innovation efficiency? [J/OL]. Modern Economic Research, 2022(12): 79-90. https://doi.org/10.13891/j.cnki.mer.2022.12.009

[23] XIN L, MENG X T, BIAN W T. A study on the dual network embedding and innovation performance of Chinese digital economy enterprises [J/OL]. Finance and Trade Research, 2022, 33(12): 59-73. https://doi.org/10.19337/j.cnki.34-1093/f.2022.12.006

[24] TANG Y J, WANG Y, TANG C H. Digital economy, market structure and innovation performance [J/OL]. China Industrial Economy, 2022(10): 62-80. https://doi.org/10.19581/j.cnki.ciejournal.2022.10.004

[25] DONG X S, WANG J M, XIAO X. How does the digital economy affect technological innovation of manufacturing enterprises—From the perspective of the "digital divide" [J/OL]. Economist, 2022(11): 62-73. https://doi.org/10.16158/j.cnki.51-1312/f.2022.11.013

[26] ZHANG J J. Digital finance, technological innovation and corporate competitiveness—Empirical evidence from listed enterprises in China [J]. Southern Finance, 2023: 1-15.

[27] LANG X X, ZHANG M M, WANG J N. Digital inclusive finance, financing constraints and innovation of small and medium-sized enterprises—A study based on the data of the New Third Board enterprises [J]. Southern Finance, 2021(11): 13-25.

[28] ZHAO T, ZHANG Z, LIANG S K. Digital economy, entrepreneurial activity and high-quality development—Empirical evidence from Chinese cities [J/OL]. Management World, 2020, 36(10): 65-76. https://doi.org/10.19744/j.cnki.11-1235/f.2020.0154

[29] LI Z S, JIN L. Does bank competition improve corporate investment levels and resource allocation efficiency?—A study based on the spatial distribution of bank branches [J]. Financial Research, 2021(1): 111-130.

[30] TANG S, WU X C, ZHU J. Digital finance and corporate technological innovation—Structural characteristics, mechanism identification and the difference in regulatory effects [J/OL]. Management World, 2020, 36(5): 52-66+9. https://doi.org/10.19744/j.cnki.11-1235/f.2020.0069

[31] SUN F C, WU G L, JIANG S Q. A study on the impact of digital inclusive finance on corporate investment efficiency [J/OL]. East China Economic Management, 2023, 37(1): 95-107. https://doi.org/10.19629/j.cnki.34-1014/f.220328003

[32] GOMBER P, KAUFFMAN R J, PARKER C, et al. On the Fintech Revolution: Interpreting the forces of innovation, disruption, and transformation in financial services [J/OL]. Journal of Management Information Systems, 2018, 35(1): 220-265. https://doi.org/10.1080/07421222.2018.1440766

[33] ZHANG Z Y, MA Y F. Digital finance and corporate investment: A bank risk-taking perspective [J/OL]. Contemporary Economic Science, 2023, 45(1): 61-73. https://doi.org/10.20069/j.cnki.DJKX.202301005

[34] JIANG H L, HOU Y, JIANG P C. Does digital economic development promote or inhibit corporate physical investment?—Empirical evidence from listed companies in China [J/OL]. Modern Finance (Journal of Tianjin University of Finance and Economics), 2022, 42(5): 78-94. https://doi.org/10.19559/j.cnki.12-1387.2022.05.004

[35] WU Y, DONG J. Venture capital and corporate innovation: Effect evaluation and mechanism verification [J/OL]. Shanghai Economic Research, 2022(4): 112-128. https://doi.org/10.19626/j.cnki.cn31-1163/f.2022.04.011