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Research on the Impact of Digital Finance on Technological Innovation Under the Background of Green Development - an Example of the Listed Automobile Manufacturing Industry

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Abstract: This paper focuses on exploring the role of digital finance in corporate technological innovation, how it influences technological innovation, and the manifestation of green development in this process. The study centers on China's listed automotive manufacturing enterprises and is based on data from Chinese A-share automotive manufacturing companies listed from 2011 to 2023, examining the mechanism by which digital finance affects technological innovation and the moderating effect of green development level. The research results obtained in this paper show that: (1) Digital finance can promote technological innovation in enterprises, and the effect is obvious. It achieves this by optimizing the allocation of resources to make them more reasonably distributed and reducing the cost required for enterprise financing. In this way, digital finance can effectively enhance the technological innovation capabilities of automotive manufacturing enterprises. (2) Its core mechanism is mainly to alleviate the constraints that enterprises encounter in financing, provide very crucial financial support for the innovation activities of typical capital-intensive industries such as the automotive manufacturing industry, and enable these innovation activities to proceed smoothly. (3) The level of green development of enterprises will positively regulate this relationship. In the automotive manufacturing industry, where the pressure of green transformation is relatively high, the better the environmental performance of those enterprises, the more obvious the impact of digital finance.

Keywords: Digital Finance; Technological Innovation; Green Development

1 Introduction

In the 21st century, green development has become a globally recognized concept. The 2022 Central Economic Work Conference further emphasized the importance of maintaining a steady and progressive approach, promoting the transition toward a green economy, and synergistically advancing carbon reduction, pollution control, ecological expansion, and economic growth[1]. According to the "2023 Green Development Report" released by the Beijing News Zero Carbon Institute, in November 2023, the Ministry of Industry and Information Technology (MIIT) newly designated 1,491 green factories, 104 green industrial parks, and 205 green supply chain management enterprises. From 2012 to 2021, China's manufacturing sector accounted for approximately 30% of the global manufacturing value-added, maintaining the top position worldwide for 14 consecutive years[2]. Digital finance enhances information transparency and sharing, reduces transaction costs, and improves market efficiency. For the manufacturing sector, it enables enterprises to access information related to green technologies more easily, accelerating

the promotion and application of new technologies. Within the broader context of promoting green development, digital finance plays a facilitative role in technological innovation, which is particularly pronounced in the automobile manufacturing industry. In the first half of 2023, China's new energy vehicle (NEV) segment continued its rapid growth, with production and sales reaching 3.788 million and 3.747 million units, surging by 42.4% and 44.1% year-on-year, respectively. Consequently, NEVs accounted for 28.3% of all new car sales during this period. Additionally, automobile exports reached 2.14 million units, a substantial increase of 75.7% compared to the same period last year. As an innovative form of financial service, digital finance provides efficient and convenient financial support for the research and application of green technologies. For instance, crowdfunding for green projects through digital platforms can rapidly pool social capital, thereby promoting the innovation and advancement of green technologies.

Amid the rapid growth of digital finance and the strong promotion of green transition, exploring how to leverage the advantages of digital finance to maximize its positive environmental impact, incentivize enterprises to pursue green technological innovation, and thereby achieve high-quality economic development has become a crucial and urgent issue. Therefore, it is of great necessity to conduct an in-depth study on the impact of digital finance on corporate technological innovation and its mechanisms within the context of green development. This study will investigate the impact of technological innovation from a comprehensive perspective that integrates green development and digital finance. Taking automotive manufacturing enterprises as an example, this research will delve into how digital finance promotes technological innovation under the "dual-carbon" goals, aiming to tailor specific technological upgrading and innovation strategies for these enterprises. This will help enhance their green competitiveness.

This study investigates how digital-finance penetration (DFP) shapes green technological innovation (GTI) in China’s A-share listed automobile-manufacturing sector from 2011 to 2023, embedding the analysis within the green-development paradigm to test (i) the net effect of DFP on green patents and carbon-efficient product launches after disentangling its risk-pooling, data-driven screening benefits from potential short-termist or algorithmic-bias costs, (ii) the moderated-mediation channel through which green investment transmits the DFP–GTI linkage under varying market-oriented incentives (e.g., emissions-trading premiums) and policy shocks (e.g., dual-credit regulation), and (iii) the industry heterogeneity of these relationships across whole-vehicle, power-train, parts and new energy sub sectors by exploiting firm-level technological intensity, asset structure and regional green-finance pilot differentials, while treating financing constraints—proxied by the SA index interacted with green-credit availability as a simultaneous mediator and regional green development intensity—captured by carbon-trading prices and environmental-tax stringency as a contextual moderator within framework.

2 literary review

2.1 Digital Finance

Li and Zhang (2024) define digital finance as a product of the deep integration between the financial sector and digital technologies. Driven by key areas such as digital currency, inclusive finance, fintech, and

blockchain technology, digital finance promotes innovation and widespread adoption of financial services[3]. Similarly, Gomber et al. (2017) explicitly state that digital finance refers to a financial model that innovates and transforms traditional financial services through digital technologies and fintech means[4]. It encompasses emerging financial service models such as mobile payments, online crowdfunding, and P2P lending, aiming to enhance the efficiency and accessibility of financial services. This study adopts the perspective of Wang and Qi (2024), who propose using the Peking University Digital Financial Inclusion Index to measure digital finance indicators[5].

2.2 Green Development

Ding et al. (2023) define green development as investments in economic activities aimed at environmental improvement, climate change mitigation, and efficient resource utilization. These activities encompass financial services supporting project financing, operation, and risk management in fields such as environmental protection, energy conservation, clean energy, green transportation, and green building[6]. Similarly, Muhammad and Hoffmann (2024) describe green development as economic activities that promote environmental improvement, address climate change, and enhance resource efficiency. These activities include financial services facilitating investment, operation, and risk management in areas like environmental protection, energy efficiency, clean energy, green transportation, and green building[7]. Zhang Wei et al. (2024) define it as green investments at the corporate level, which signify a transition toward a sustainable economic development model. These investments form the foundation for green transformation and innovation and represent the first step toward achieving carbon peak goals and societal energy-saving and emission-reduction targets[8]. Yang and Hui (2024) view green development as an integral part of corporate green innovation activities, emphasizing their growing importance due to their critical role in fostering sustainable enterprise development and environmental protection[9].

2.3 Economic Development Innovation

According to Chen and Wu (2023) describe technological innovation as being reflected through the measurement of resource input and output efficiency. This involves not only the examination of R&D activities themselves but also the evaluation of output results[10]. Lan Lixue (2024) views technological innovation as the application of big data and artificial intelligence, which has become a key driver of corporate innovation performance. The role of technological innovation, R&D investment, and other factors in promoting innovation performance, as well as the mediating effects among these factors, are key research focuses in this field[11]. Ma Xinyue (2023) argues that technological innovation is a primary driver for enterprises to gain a competitive advantage, and sustained capital investment is a crucial guarantee for successful technological innovation. The study uses the number of patent applications to represent corporate technological innovation, and this paper adopts this perspective[12].

2.4 Financing Constraints

Ma Xinyue (2023) points out that when raising funds, enterprises typically prioritize internal financing, followed by borrowing, and finally consider external investment. This preference arises because external financing may expose operational weaknesses and incur additional costs. However, internal capital

accumulation is often limited by factors such as operational scale and profitability, making it difficult to simultaneously support daily operations and R&D investments. Consequently, external funding sources become crucial for technological innovation[12]. This study adopts this perspective. Zeng Xuejing (2022) further notes that when faced with financing constraints, enterprises are often forced to seek high-cost external financing channels, leading to a passive increase in their debt levels[13].

3 Theoretical Analysis and Research Hypotheses

3.1 Impact of Digital Finance on Corporate Technological Innovation

In summary, digital finance functions like a "funding highway" for technological innovation, enabling promising ideas to secure financial support more easily and allowing innovators to focus less on funding constraints, thereby significantly enhancing overall societal innovation vitality. This facilitative effect is particularly evident among small and medium-sized enterprises (SMEs). The application of digital technologies has expanded the coverage of financial services, bridging the physical distance between financial institutions and clients through online banking services. This effectively addresses the long-standing challenges of "difficulty and high cost of financing" faced by small, medium, and micro enterprises, while substantially reducing financial transaction costs[13]. As costs decrease, enterprises are more inclined to develop newer and more people-friendly financial products, thereby further elevating technological innovation capabilities. Based on the above analysis, the following hypothesis is proposed:

H1: Digital finance has a positive impact on technological innovation.

3.2 Financing Constraints in How Digital Finance Affects Tech Innovation

Corporate technological innovation activities are characterized by high investment, long cycles, and significant risks. They require sustained inputs of substantial human, material, and financial resources, as well as long term R&D accumulation, posing severe challenges for resource-constrained small and medium-sized enterprises[14]. Due to the high uncertainty and information asymmetry associated with innovation activities, traditional financial institutions are often reluctant to provide financing support for innovative projects of SMEs. The traditional banking-centric financial system exhibits significant limitations: on one hand, banks tend to have conservative risk preferences, overly relying on physical collateral such as real estate while neglecting enterprises' growth potential; on the other hand, underdeveloped direct financing channels restrict the funding options for SMEs. Thus, the following hypothesis is proposed:

H2: Digital finance enhances corporate R&D and innovation by alleviating financing constraints.

3.3 Green Development as a Moderator of Digital Finance's Impact on Tech Innovation

To advance the "dual-carbon" goals, governments at all levels have introduced supportive policies for green development. For instance, green technology innovation projects may receive subsidies, tax incentives, and other policy supports. The combination of these policies and digital finance can provide more robust support for corporate technological innovation[18]. When enterprises with high green development levels seek financing through digital channels, they often benefit from government guarantees or subsidies, adding an extra layer of security. For example, companies engaged in environmentally

friendly equipment manufacturing, whose activities align with national policy directions, are perceived as more reliable by banks and investors. This enhances trust and investment willingness, making it easier for such enterprises to secure support through digital finance platforms[16]. Based on this analysis, the following hypothesis is proposed:

H3: Green development amplifies digital finance's effect on innovation.

In summary, based on the aforementioned three hypotheses and referencing studies by Feng Fang (2023) and Zhao Mao et al. (2025), a preliminary model is constructed as shown in Figure 1[15,16]:

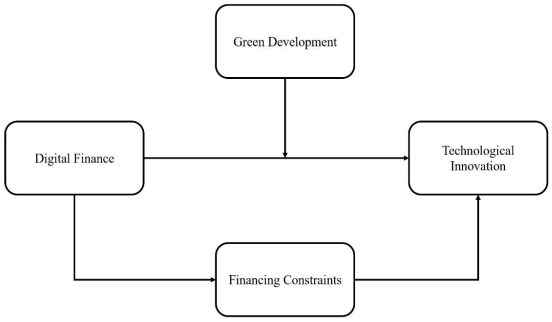

Fig. 1 Research Hypothesis Model

4 Research Design

4.1 Simple Selection and Data Sources

This study employs data from Chinese A-share listed companies in the automobile manufacturing industry spanning the period 2011 to 2023 for empirical analysis. To ensure the scientific rigor of the econometric analysis and the completeness of the data, the following processing steps were applied: Excluded ST and *ST companies; Removed enterprises with missing data; Applied a 1% bilateral winsorization to mitigate the influence of outliers. After processing, 802 firm-year observations were retained. The data on listed companies were sourced from the CSMAR Database, patent application counts from the CNRDS Database, green development metrics from the China Securities ESG Database, and digital finance data from the Peking University Digital Financial Inclusion Index.

4.2 Variable Selection

(1) Explained Variable: this study employs corporate patent applications (lnpatent) to measure technological innovation as the explained variable. The data are logarithmically transformed after adding 1. (2) Explanatory Variable: Drawing on the research of Ma Xinyue (2023), the Digital Financial Inclusion Index (lndigit) is adopted to measure digital finance as the explanatory variable[12]. The data are logarithmically processed. (3) Moderating Variable: Based on the study of Zhao Mao et al. (2025), corporate environmental responsibility (green) is selected as the moderating variable, representing the level of green development. Specifically, the environmental responsibility dimension of the ESG indicator is used to quantify corporate green development[16]. (4) Mediating Variable: Following the approach of Wang Wenjing and Qi Shuopeng (2024), financing constraints (sa) are used as the mediating variable, measured by the SA (Size-Age) index of financing constraints[5]. The absolute value of the index is taken, where a

larger SA index indicates a higher level of financing constraints faced by the enterprise, and vice versa. (5) Control Variables: The following control variables are included: Firm size, Fixed asset ratio, Largest shareholder ownership, Listing age, Profitability, Financial leverage, Growth capability, Proportion of independent directors, Duality of the CEO and chairperson roles.

4.3 Model Construction

To verify whether digital finance promotes the improvement of corporate technological innovation levels, this study draws on the research of Zhao Mao et al. (2025) and employs a fixed-effects model to construct the baseline regression model as follows[16]:

$$\ln patent_{it} = \beta_1 \ln digit_{it} + \sum \gamma^j cvs_{it}^j + \sum YEAR + \sum Firm + \alpha_0 + \varepsilon_{it} \quad (1)$$

In the model, t denotes the enterprise, t denotes the year, β_1 represents the estimated coefficient of the explanatory variable, i indicates the number of control variables, γ represents the estimated coefficients of the control variables, cvs_{it}^j denotes the set of control variables, α_0 is the intercept term, and ε_{it} is the random error term.

To examine the moderating effect of green development on the relationship between digital finance and technological innovation, the moderating variable and its interaction term with the explanatory variable are incorporated into the baseline regression model. The model specification is shown in Model (2):

$$\ln patent_{it} = \beta_1 sa_{it} \times \ln digit_{it} + \beta_2 sa_{it} + \beta_3 digit_{it} + \sum \gamma^j cvs_{it}^j + \sum YEAR + \sum Firm + \alpha_0 + \varepsilon_{ii} \quad (2)$$

In the above model, if β_1 ,the estimated coefficients, pass the significance test, it indicates that the moderating mechanism is established.

For the mechanism test, this study refers to the three-step mediation test method proposed by Wen Zhonglin and Ye Baojuan (2014) based on the baseline regression model[17]. The first step corresponds to the aforementioned baseline regression model, as shown in Model (3):

$$\ln patent_{it} = \beta_1 \ln digit_{it} + \sum \gamma^j cvs_{it}^j + \sum YEAR + \sum Firm + \alpha_0 + \varepsilon_{it} \quad (3)$$

The second step involves the regression model of the explanatory variable on the mediating variable, as shown in Model (4):

$$sa_{it} = \beta_2 \ln digit_{it} + \sum \gamma^j cvs_{it}^j + \sum YEAR + \sum Firm + \alpha_0 + \varepsilon_{it} \quad (4)$$

The third step involves the regression model of the mediating variable on the explained variable, as shown in Model (5):

$$\ln patent_{it} = \beta_3 sa_{it} \times \beta_4 \ln digit_{it} + \sum \gamma^j cvs_{it}^j + \sum YEAR + \sum Firm + \alpha_0 + \varepsilon_{it} \quad (5)$$

5 Empirical Analysis

5.1 Descriptive Statistics

Table 1 Descriptive Statistics

Variable Name	Data volume	Average value	Standard deviation	Minimum value	Median	Maximum value
Technological innovation	802	4.285	1.802	0.000	4.248	8.144
Digital finance	802	5.365	0.452	3.997	5.506	5.906

Table 1 Descriptive Statistics (continued)

Green development	802	0.679	0.049	0.532	0.684	0.773
Financing constraints	802	3.747	0.266	2.805	3.764	4.379
Enterprise scale	802	22.857	1.416	19.918	22.682	27.104
Proportion of fixed assets	802	0.208	0.091	0.034	0.197	0.464
Shareholding by major shareholders	802	0.575	0.148	0.250	0.564	0.928
Age at listing	802	13.985	7.438	1.000	14.000	29.000
Profitability	802	0.032	0.051	-0.171	0.033	0.141
Financial leverage	802	0.501	0.167	0.121	0.512	0.904
Development capacity	802	0.094	0.243	-0.537	0.092	1.061
Proportion of independent directors	802	0.365	0.046	0.333	0.333	0.533
Two positions combined	802	0.246	0.431	0.000	0.000	1.000

Table 1. The following insights can be drawn: The mean value of technological innovation (lnpatent) is 4.285, with a standard deviation of 1.802, indicating significant differences in technological innovation among sample enterprises. The mean value of digital finance (lndigit) is 5.365, with a standard deviation of 0.452, suggesting moderate variation in digital finance levels across enterprises. The mean value of green development (green) is 0.679, with a standard deviation of 0.049, reflecting relatively consistent performance in green development among enterprises.

5.2 Model Testing

Table 2 Model Test Results

Inspection method	Statistics	P value	Inspection conclusion
F-test	25.72	0.00	The fixed-effect model is superior to the hybrid OLS model
Hausman test	51.15	0.00	The fixed effects model is superior to the random effects model

As shown in Table 2, the F-test (statistic = 25.72, p = 0.00) strongly rejects the hypothesis that "the pooled OLS model is superior", indicating the presence of significant individual effects in the data. The Hausman test result (statistic = 51.15, p = 0.00) further confirms that the fixed-effects model is preferable to the random-effects model, suggesting that the individual effects are correlated with the explanatory variables. Given that the fixed-effects model is optimal for this study.

5.3 Baseline Regression Analysis

As shown in Table 3, Column (1) indicates that the coefficient of digital finance on technological innovation (lnpatent) is 1.025, significant at the 0.001 level, suggesting a significant positive impact of digital finance on technological innovation. In Column (2), the coefficient of digital finance (lndigit) decreases to 0.364 but remains significant at the 0.001 level, indicating that the positive effect of digital finance on technological innovation persists even after controlling for additional variables. In Column (3), the analysis of the coefficient shows that the estimated coefficient for the digital finance (lndigit) variable is 2.034, passing the 1% significance test. This implies that a 1% increase in digital finance leads to a 2.034 percentage point increase in R&D innovation among automobile manufacturing enterprises.

Table 3 Baseline Regression Results

	(1)	(2)	(3)
	Technological innovation	Technological innovation	Technological innovation
Digital finance	0.824***	0.364***	2.034***
	(0.152)	(0.130)	(0.732)
Shareholding by major shareholders	1.787***	-1.340***	0.328
	(0.406)	(0.353)	(0.441)
Age	0.033***	-0.011	-0.402**
	(0.010)	(0.009)	(0.204)
Proportion of independent directors	4.196***	1.094	-1.027
	(1.375)	(1.105)	(1.021)
Two positions combined	-0.515***	-0.391***	0.156
	(0.151)	(0.121)	(0.110)
Enterprise scale		0.857***	0.796***
		(0.046)	(0.077)
Proportion of fixed assets		0.730	-0.248
		(0.582)	(0.661)
Profitability		3.408***	0.540
		(1.142)	(0.911)
Financial leverage		-0.073	0.141
		(0.370)	(0.410)
Development capacity		-0.467**	-0.220*
		(0.210)	(0.133)
Constant	-3.033***	-16.815***	-19.424***
	(0.924)	(0.988)	(3.940)
"Individual	No	No	Yes
Year	No	No	Yes
N	802	802	802
R^2	0.127	0.457	0.386

( )robust standard errors in parentheses; *p < 0.1 , ** p < 0.05, *** p < 0.01;

5.4 Robustness Test

Specifically, invention patents were used to replace total patents (lnpatent 2) to construct a robustness test by altering the explained variable. The results, presented in Column (1) of Table4, show that the coefficient of digital finance (lndigit) is 1.814, which is significantly positive at the 0.05 level. The results are presented in Columns (2) and (3) of Table 11. As shown in Column (2), the coefficient for digital finance (lndigit) is 1.429, significant at the 0.01 level, indicating a significantly positive impact on technological innovation. In Column (3), the coefficient for digital finance (lndigit) is 2.780, significant at the 0.001 level, further confirming its significantly positive effect on technological innovation. Both variables—coverage breadth (lnbreadth) and usage depth (lndepth)—exhibit significantly positive coefficients, consistent with the baseline regression results.

Table 4 Robustness Checks

	(1)	(2)	(3)
	Total patent	Technological innovation	Technological innovation
Digital finance	1.814**		
	(0.774)		
Coverage breadth		1.429***	
		(0.470)	
Use depth			2.780***
			(0.613)
Enterprise scale	0.633***	0.784***	0.846***
	(0.081)	(0.077)	(0.077)
Proportion of fixed assets	-0.402	-0.216	-0.196
	(0.699)	(0.659)	(0.654)
Shareholding by major shareholders	1.519***	0.371	0.154
	(0.466)	(0.440)	(0.439)
Age at listing	-0.532**	-0.385*	-0.452**
	(0.216)	(0.204)	(0.203)
Profitability	0.165	0.556	0.704
	(0.964)	(0.910)	(0.902)
Financial leverage	0.577	0.183	0.112
	(0.433)	(0.411)	(0.405)
Development capacity	-0.359**	-0.219	-0.251*
	(0.141)	(0.133)	(0.132)
Proportion of independent directors	-0.907	-1.140	-0.692
	(1.080)	(1.020)	(1.016)
Two positions combined	0.230**	0.162	0.124
	(0.117)	(0.110)	(0.108)

Table 4 Robustness Checks (continued)

Constant	-15.941***	-16.912***	-23.379***
	(4.167)	(3.122)	(3.646)
Individual	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	802	802	802
R2	0.380	0.387	0.397

( )robust standard errors in parentheses; *p < 0.1 , ** p < 0.05, *** p < 0.01;

6 Research Conclusions and Recommendations

6.1 Conclusions

Based on data from Chinese A-share listed companies in the automobile manufacturing industry from 2011 to 2023, this study explores the impact mechanism of digital finance on technological innovation within the context of green development. The findings reveal that: (1) Digital finance significantly enhances corporate technological innovation by broadening financing channels and reducing information asymmetry, with a more pronounced effect on non-state-owned enterprises. (2) Financing constraints serve as a core mechanism, as digital finance indirectly promotes R&D investment by alleviating corporate financial pressures. (3) Green development level exhibits a positive moderating effect, where enterprises with stronger environmental performance experience a greater promoting effect of digital finance on technological innovation.

6.2 Recommendations

In terms of policy recommendations, it is essential to improve the digital financial infrastructure. Governments should facilitate the alignment between digital finance platforms and green projects, develop specialized credit products, and provide differentiated interest rate support to environmentally friendly enterprises. Additionally, governments ought to flexibly adjust financial and green development policies in response to changes in the policy environment, thereby maximizing the promoting effect of digital finance on technological innovation. To strengthen green policy incentives, corporate ESG performance should be incorporated into the credit evaluation system of digital finance. Enterprises with high green development levels should be granted higher loan quotas and interest subsidy ratios. Furthermore, it is crucial to optimize the financing environment by encouraging collaboration between banks and fintech companies. Utilizing big data risk control models can reduce reliance on collateral, with particular emphasis on supporting innovation projects of small and medium-sized enterprises. Cross-industry cooperation should be promoted to share best practices in digital finance and technological innovation, accelerating the diffusion and application of advanced technologies. For enterprises, there are several key implications: Proactively embrace digital transformation: Enterprises should actively engage with digital finance platforms to leverage their efficient financing functions for long-term R&D support. Deepen green technology disposition: Convert environmental protection investments into financing advantages, forming a virtuous cycle from green performance to capital acquisition and ultimately to innovation upgrading.

6.3 Research Limitations and Future Prospects

While this study has yielded certain findings, several limitations remain to be addressed: (1) The research is confined to listed companies in China's A-share automobile manufacturing industry, which may not fully capture the realities of other industries or regions. (2) Data limitations were encountered during the study, with coverage limited to the period from 2011 to 2023, failing to reflect the latest developments. (3) The findings are primarily derived from the Chinese context, potentially raising concerns about external validity. Further validation across different countries and regions is necessary.

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