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# The Impacts of Digital Finance on Corporate Innovation Efficiency -- Empirical Evidence from China

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## Abstract

**Based on data from listed companies in China's Shanghai and Shenzhen A-shares from 2016 to 2020, this study empirically investigates the impact of digital finance on corporate innovation efficiency and its underlying mechanisms using fixed effects models and mediation effect models. The results indicate that digital finance can enhance corporate innovation efficiency, which remains robust after sensitivity tests. Mediation analysis reveals that digital finance promotes innovation efficiency by alleviating financing constraints and financial distress. Heterogeneity tests show that the positive impact of digital finance on innovation efficiency is more pronounced in non-state-owned enterprises, small and medium-sized enterprises, companies located in central and western regions, non-first-tier cities, areas with lower levels of marketization. This research provides valuable policy insights for advancing the adoption of digital financial technologies and enhancing corporate innovation efficiency.**

## Keywords

**Digital Finance; Corporate Innovation Efficiency; Financing Constraints; Financial Distress.**

## 1. Introduction

In an era characterized by rapid advancements in digital technology, corporate innovation has emerged as a pivotal driver for enhancing market competitiveness, which fosters sustainable economic development. The growth of corporate innovation is heavily reliant on robust financial support. However, given the high-risk nature and significant capital requirements of innovation activities, traditional financial systems often fail to meet these needs. The integration of digital technologies such as the Internet and big data with the financial sector has led to the rise of digital finance, which offers broader coverage, lower service costs, and greater inclusivity compared to traditional finance. Consequently, the role of digital finance in fostering corporate innovation has garnered increasing scholarly attention.

Existing literature primarily examines the effects of factors such as financing structure, environmental regulations, government innovation subsidies, risk-taking, and digital transformation on corporate innovation efficiency. For instance, Yang Jie et al. (2022) assert that digital transformation enhances corporate innovation levels by increasing risk-taking, which is further supported by Chen Xiude et al. (2023), indicating that digital finance positively influences innovation efficiency [1, 2]. However, some scholars present opposing views. Yang Yaping et al. (2021) argue that corporate investment negatively impacts innovation [3]. This is approved by Sun Fangcheng et al. (2023), who suggest that digital finance may also lead to over-investment while alleviating under-investment [4]. This divergence raises the question: Does digital finance positively or negatively impact corporate innovation efficiency, and what are the intrinsic mechanisms behind this impact? Current research lacks consensus.Therefore, this

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study leverages the digital finance index and data from listed companies in China's Shanghai and Shenzhen A-shares from 2016 to 2021, employing fixed effects models and mediation effect models for regression analysis. The aim is to empirically assess the impact of digital finance on corporate innovation efficiency and elucidate the underlying mechanisms and pathways.

The innovations of this paper are reflected in three aspects. First, while existing studies on corporate innovation focus predominantly on the quantity, quality, inputs, and outputs of innovation, few investigate innovation efficiency. This study examines the impact of digital finance on innovation efficiency, further extending current research and providing significant insights into the sustainable development of digital finance and the enhancement of corporate innovation capabilities. Second, most existing studies explore the mediating effect of financing constraints but rarely address financial distress. This study introduces both financing constraints and financial distress as mediating variables to further explore the mechanisms of digital finance's influences on innovation efficiency. Third, unlike most studies that focus on variables such as ownership structure and regional differences in heterogeneity analysis, this study includes additional variables such as city classification, company size, and marketization level, making the research more comprehensive and innovative.

## 2. Theoretical Analysis and Research Hypotheses

### 2.1. Digital Finance and Corporate Innovation Efficiency

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

Regarding the relationship between digital finance and corporate innovation efficiency from the perspective of direct effects, Shen Minghao et al. (2022) argue that digital finance can augment corporate innovation investments, further enhancing innovation performance and overall innovation levels [5]. Moreover, Li Jian et al. (2020), based on resource allocation theory, suggest that digital financial inclusion activates financial resources beyond the formal financial system and increases their liquidity, effectively expanding corporate financing channels and boosting innovation vitality [6]. Yang Yaping et al. (2021) infer that traditional financial investment behaviors have a significantly negative impact on corporate innovation. However, digital finance can facilitate the rational allocation of financial resources by mitigating the problem of over-investment, thereby fostering corporate innovation. Furthermore, Chen Xiude et al. (2023) emphasize that digital finance can provide precise risk assessments for companies with its risk identification capabilities, which helps to alleviate information asymmetry during the financing process, thereby increasing the company's capacity to undertake risky investments. Consequently, it could be the case that digital finance stimulates innovation activities and improves innovation levels.

From an indirect effects perspective, Xiao Hongjun et al. (2022) suggest that digital finance can promote corporate digital transformation [7]. On one hand, during the digital transformation process, companies can leverage technologies such as blockchain and big data to enhance management efficiency. On the other hand, digital technologies can improve information quality, thereby increasing corporate transparency and mitigating information asymmetry. Both aspects are conducive to fostering corporate innovation and enhancing innovation efficiency. In addition, Liu Lifu et al. (2022) demonstrate that digital finance can reduce

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corporate financing costs and expand cash flow, further improving total factor productivity and promoting investment in innovation [8].

However, digital finance may also have negative impacts on corporate innovation efficiency. Shen Minghao et al (2022) argue that due to the diminishing returns from technological imitation and low-value innovation, while the quantity of corporate innovation in China is high, the quality remains low. Their research indicates that the development of digital finance may inhibit strategic innovation, potentially lowering the quality and efficiency of innovation. Based on the above analysis, this paper proposes the following hypothesis:

H1: Digital finance can enhance corporate innovation efficiency.

### 2.2. Digital Finance, Financing Constraints and Corporate Innovation Efficiency

Corporate innovation activities rely on ample financial resources from capital markets and innovation capabilities as well as levels require financial resources as crucial support for sustainable development. Shen Minghao et al (2022) assert that digital finance can effectively alleviate corporate financing constraints, enabling access to more innovation market resources. Moreover, Zhou Zhenjiang (2021) et al. further point out that companies' willingness to innovate is suppressed when faced with financing constraints [9]. In contrast, through its integration with big data, the internet, and cloud computing, digital finance effectively broadens corporate financing channels, providing financial support for innovation activities. Furthermore, digital finance can mitigate the inefficiencies caused by information asymmetry in traditional finance, overcoming geographical limitations and expanding service groups, thereby providing more financing sources for enterprises. In addition, Wan Jiayu (2020) et al. also argue that information asymmetry restricts external financing behaviors whose effectiveness determines the financial support for innovation activities [10]. One possible implication is that digital finance alleviates financing constraints by leveraging emerging technologies for information matching, providing financial support for corporate innovation. On top of that, Tang Song (2020) et al. believe that digital finance resolves structural mismatches in traditional finance, mitigating financial resource stratification and lifting constraints on corporate innovation development [11]. Based on the above analysis, this paper proposes the following hypothesis:

H2: Digital finance enhances corporate innovation efficiency by alleviating financing constraints.

### 2.3. Digital Finance, Financial Distress, and Corporate Innovation Efficiency

According to resource dependence theory, financial distress inhibits corporate innovation development. Zhang Jinchang et al. (2020) theorize that financial distress occurs when a company is unable to meet its debt obligations, which is a dynamic process ranging from cash shortages and payment difficulties to financial crises, debt defaults, corporate bankruptcy, and operational failure [12]. Ma Wenting et al. (2023) conclude that developing digital finance can improve mismatched financing terms, thereby alleviating financial distress, reducing resource misallocation, and providing sufficient innovative resources for corporate research and development [13]. Based on the above analysis, this paper proposes the following hypothesis:

H3: Digital finance enhances corporate innovation efficiency by alleviating financial distress.

## 3. Research Design

### 3.1. Data Sources and Processing

This study selects data from listed companies in China's A-shares from 2016 to 2021 as the research sample for empirical analysis. To ensure the representativeness of the sample data, the following treatments are applied:

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(1) Exclude samples from listed companies in the financial industry, such as insurance, banking, and securities.

(2) Exclude samples from companies with significant operational issues, such as ST, *ST, and PT companies.

(3) Exclude samples from companies listed for 12 months or less, as well as those with missing relevant data.

(4) Apply 1% winsorization to all continuous variables to eliminate the impact of outliers.

After these treatments, a total of 18,544 sample observations are obtained. All raw data are sourced from the CSMAR and CNRDS databases. The digital finance index is compiled by a joint research team from the Digital Finance Research Center of Peking University and the Ant Financial Group Research Institute.

## 3.2. Variable Definitions

### 3.2.1. Dependent Variable

The dependent variable in this study is corporate innovation efficiency (InnoEff), which is categorized into four levels. Innovation efficiency 1 (InnoEff1) is the primary dependent variable, while innovation efficiency 2 (InnoEff2), innovation efficiency 3 (InnoEff3), and innovation efficiency 4 (InnoEff4) are used as alternative variables for robustness checks.

Innovation Efficiency 1 (InnoEff1): Measured by the ratio of the natural logarithm of the total number of patent applications (including invention patents, utility model patents, and design patents) plus one to the natural logarithm of R&D expenditure plus one.

Innovation Efficiency 2 (InnoEff2): Calculated using the natural logarithm of weighted total number of patent applications (with weights of 3:2:1 for invention patents, utility model patents, and design patents, respectively) plus one to the natural logarithm of R&D expenditure plus one.

Innovation Efficiency 3 (InnoEff3): Measured by the ratio of the natural logarithm of the number of invention patent applications plus one to the natural logarithm of R&D expenditure plus one.

Innovation Efficiency 4 (InnoEff4): Measured by the ratio of the natural logarithm of the number of utility model and design patent applications plus one to the natural logarithm of R&D expenditure plus one.

### 3.2.2. Independent Variable

The independent variable in this study is digital finance (DF). The provincial-level digital inclusive finance index, compiled by a joint research team from the Digital Finance Research Center of Peking University and the Ant Financial Group Research Institute, is used as a proxy indicator for digital finance.

### 3.2.3. Mediating Variables

Corporate Financing Constraints (KZ): This study employs the KZ index to measure corporate financing constraints, which was proposed by Kaplan and Zingales (1997) [14]. This is a positive indicator, meaning the larger the KZ index, the greater the financing constraints faced by enterprises; conversely, a smaller KZ index indicates fewer financing constraints.

Corporate Financial Distress (Zscore): This study adopts the financial distress prediction model proposed by Altman (1968) and follows the methodology of Ma Wenting et al. (2021) to measure corporate financial distress using the Zscore index [15]. This is a negative indicator, meaning the larger the Zscore index, the lower the probability of financial distress; conversely, a smaller Zscore index indicates a higher probability of financial distress.

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### 3.2.4. Control Variables

To avoid the influence of other variables on corporate innovation efficiency, the following micro-level control variables are selected based on existing literature:

(1) Corporate Age (Age): Measured by the natural logarithm of the number of years since the company's establishment.

(2) Cash Flow (Cash): Measured by the ratio of net cash flow from operating activities to total assets.

(3) Financial Leverage (Lev): Measured by the ratio of total debt to total assets.

(4) Ownership Concentration (Top1): Represented by the shareholding ratio of the largest shareholder.

(5) Corporate Size (Size): Measured by the natural logarithm of total assets.

(6) Ownership Nature (SOE): A dummy variable assigned a value of 1 if the company is state-owned, and 0 otherwise.

(7) Growth (Growth): Measured by the revenue growth rate.

Additionally, this study controls for relevant macro-level variables:

(8)Per Capita GDP (lnGDP): Measured by the natural logarithm of per capita GDP.

Based on the above explanations, the definitions and calculation methods of the main research variables are referring to table 1:

**Table 1.** Definitions of main research variables

| Variables | Name | Description |
|---|---|---|
| InnoEff1 | Innovation Efficiency 1 | Natural logarithm of the total number of patent applications (including invention patents, utility model patents, and design patents) plus one / In (1 + R&D expenditure) |
| InnoEff2 | Innovation Efficiency 2 | Natural logarithm of weighted total number of patent applications (with weights of 3:2:1 for invention patents, utility model patents, and design patents) plus one / In (1 + R&D expenditure) |
| InnoEff3 | Innovation Efficiency 3 | Natural logarithm of the number of invention patent applications plus one / In (1 + R&D expenditure) |
| InnoEff4 | Innovation Efficiency 4 | Natural logarithm of the number of utility model and design patent applications plus one / In (1 + R&D expenditure) |
| DF | Digital Finance | Digital Financial Inclusion Index |
| KZ | Corporate Financing Constraints | KZ Index |
| Zscore | Corporate Financial Distress | Zscore Index |
| Age | Corporate Age | Natural logarithm of establishment years of corporations |
| Cash | Cash Flow | Net cash flow from operating activities / Total assets |
| Lev | Financial Leverage | Total debt / Total assets |
| Top1 | Ownership Concentration | Shareholding ratio of the largest shareholder |
| Size | Corporate Size | Natural logarithm of total assets |
| SOE | Ownership Nature | A dummy variable assigned a value of 1 if the company is state-owned, and 0 otherwise. |
| lnGDP | GDP Per Capita | Natural logarithm of GDP per capita |
| Growth | Growth | Revenue growth rate |

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### 3.3. Model Specification

This study constructs a fixed effects model to empirically examine the impact of digital finance on corporate innovation efficiency. To mitigate the impact of reverse causality, both the independent and control variables are lagged by one period. Additionally, the fixed effects of year and industry are controlled. The baseline model is as follows:

$$InnoEffit = \alpha + \beta DFi, t-1 + \sum \gamma j\ Controlj, i, t-1 + Yeart + Indi + cit \quad (1)$$

In formula (1), InnoEff represents corporate innovation efficiency; DF represents the digital finance index; Control represents the overall control variables; i represents the firm; j represents the prefecture-level city; t represents the year; and cit represents the random error term (residual).

To investigate the roles of financing constraints and financial distress in the relationship between digital finance and corporate innovation efficiency, this study refers to the method of Ba Shusong and Li Nina (2022) and establishes mediation effect models on the basis of the above model. The models are constructed as follows:

$$Mit = \alpha 1 + \beta 1 DFi, t-1 + \sum \gamma j\ Controlj, i, t-1 + Yeart + Indi + cit \quad (2)$$

$$InnoEffit = \alpha 2 + \beta 2\ Mi, t-1 + \gamma 2 DFi, t-1 + \sum \delta j\ Controlj, i, t-1 + Yeart + Indi + cit \quad (3)$$

Mit represents the overall mediating variables, specifically corporate financing constraints (KZ) and financial distress (Zscore).

## 4. Empirical Analysis

### 4.1. Descriptive Statistical Analysis

**Table 2.** Descriptive Statistical Analysis of Main Variables

| Variable | N | Mean | p50 | sd | Min | Max |
|---|---|---|---|---|---|---|
| InnoEff1 | 12393 | 0.157 | 0.168 | 0.0830 | 0 | 0.326 |
| DF | 18534 | 5.865 | 5.885 | 0.144 | 5.550 | 6.131 |
| KZ | 16100 | 0.874 | 1.153 | 2.335 | -5.877 | 6.056 |
| Zsore | 17740 | 4.728 | 3.105 | 5.234 | -0.204 | 33.41 |
| Age | 14667 | 11.95 | 10 | 7.708 | 2 | 28 |
| Cash | 18544 | 0.0500 | 0.0490 | 0.0690 | -0.160 | 0.248 |
| Lev | 14667 | 0.433 | 0.427 | 0.197 | 0.0680 | 0.900 |
| Top1 | 15753 | 33.53 | 31.10 | 14.35 | 9.170 | 73.19 |
| Size | 14667 | 22.46 | 22.28 | 1.308 | 20.06 | 26.44 |
| SOE | 18084 | 0.301 | 0 | 0.459 | 0 | 1 |
| lnGDP | 18534 | 11.38 | 11.39 | 0.395 | 10.50 | 12.12 |
| Growth | 18364 | 0.269 | 0.128 | 0.672 | -0.684 | 4.614 |

The descriptive statistical analysis results for the main variables are shown in Table 2. Table 2 shows that the minimum value of the digital finance index (DF) is 5.550, the maximum value is 6.131, the mean is 5.865, and the standard deviation is 0.144. It could be the case that the level of digital finance development is fairly uniform across different regions, with small differences. The minimum value of corporate innovation efficiency (InnoEff1) is 0, the maximum value is

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0.326, and the standard deviation is 0.083. One possible implication is that the overall innovation efficiency of enterprises is relatively low, with small differences between companies. The descriptive statistical results for the other variables are generally consistent with expectations and align with findings in existing literature.

## 4.2. The Impact of Digital Finance on Corporate Innovation Efficiency

This study employs a fixed effects model to conduct regression analysis on the impact of digital finance on corporate innovation efficiency. The baseline regression results and the regression results with control variables are shown in Table 3. Column (1) of Table 3 demonstrates that without control variables, the regression coefficient of digital finance on corporate innovation efficiency is 0.011, indicating that digital finance has a positive impact on innovation efficiency under constant year and industry conditions. Columns (2) and (3) show that after including control variables, this conclusion remains valid and is statistically significant at the 1% level. Column (2) of Table 3 illustrates that under constant year conditions, the regression coefficient of digital finance on corporate innovation efficiency is positive (0.099) and significant at the 1% level. Column (3) shows that under constant year and industry conditions, the regression coefficient of digital finance on corporate innovation efficiency is positive (0.087) and significant at the 1% level.

**Table 3.** Baseline Regression Analysis Results of the Impact of Digital Finance on Corporate Innovation Efficiency

| | (1) | (2) | (3) |
|---|---|---|---|
| Variable | InnoEff1 | InnoEff1 | InnoEff1 |
| DF | 0.011 | 0.099*** | 0.087*** |
| | (1.48) | (4.66) | (4.67) |
| Age | | -0.001*** | -0.001*** |
| | | (-10.30) | (-5.14) |
| Cash | | -0.010 | 0.007 |
| | | (-0.82) | (0.59) |
| Lev | | 0.013*** | -0.002 |
| | | (2.75) | (-0.44) |
| Top1 | | -0.000*** | -0.000*** |
| | | (-6.26) | (-2.92) |
| Size | | 0.024*** | 0.030*** |
| | | (31.29) | (42.49) |
| SOE | | 0.003 | 0.009*** |
| | | (1.48) | (4.73) |
| lnGDP | | -0.019*** | -0.020*** |
| | | (-3.68) | (-4.45) |
| Growth | | 0.000 | -0.001 |
| | | (0.29) | (-0.45) |
| Year | Yes | Yes | Yes |
| Ind | Yes | No | Yes |
| Constant | 0.035 | -0.693*** | -0.818*** |
| | (0.83) | (-9.70) | (-12.76) |
| Observations | 12,390 | 9,707 | 9,707 |
| R-squared | 0.223 | 0.187 | 0.394 |
| adj_R2 | 0.389 | 0.389 | 0.389 |
| F | 71.19 | 71.19 | 71.19 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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This demonstrates that digital finance can enhance corporate innovation efficiency, confirming Hypothesis H1 and supporting the findings of Chen Xiude et al. Moreover, it reveals that digital finance, empowered by digital technology, has improved the infrastructure and institutional support, providing favorable conditions for corporate innovation. Furthermore, digital finance has elevated financial technology development, promoting corporate innovation efficiency through continuous integration of financial technology. Driven by digital technology, digital finance has deepened digital transformation, boosting corporate self-innovation capabilities.

## 4.3. Robustness Test

### 4.3.1. Replacing the Dependent Variable

**Table 4.** Baseline Regression Analysis Results for Alternative Dependent Variables

| | (1) | (2) | (3) |
|---|---|---|---|
| Variable | InnoEff2 | InnoEff3 | InnoEff4 |
| DF | 0.096*** | 0.050*** | 0.069*** |
| | (4.49) | (2.87) | (3.73) |
| Age | -0.001*** | -0.000*** | -0.000** |
| | (-5.33) | (-3.10) | (-2.09) |
| Cash | 0.004 | -0.005 | 0.007 |
| | (0.35) | (-0.44) | (0.62) |
| Lev | -0.005 | -0.012*** | 0.016*** |
| | (-0.94) | (-2.84) | (3.72) |
| Top1 | -0.000*** | -0.000** | 0.000 |
| | (-3.65) | (-2.07) | (0.46) |
| Size | 0.032*** | 0.028*** | 0.023*** |
| | (39.58) | (41.45) | (32.05) |
| SOE | 0.010*** | 0.011*** | 0.003* |
| | (4.99) | (6.22) | (1.82) |
| lnGDP | -0.022*** | -0.007* | -0.020*** |
| | (-4.15) | (-1.72) | (-4.46) |
| Growth | -0.000 | 0.001 | -0.000 |
| | (-0.23) | (1.00) | (-0.36) |
| Constant | -0.864*** | -0.734*** | -0.583*** |
| | (-11.74) | (-12.06) | (-9.14) |
| Observations | 9,707 | 8,771 | 8,771 |
| R-squared | 0.365 | 0.322 | 0.406 |
| adj_R2 | 0.400 | 0.400 | 0.400 |
| F | 69.10 | 69.10 | 69.10 |

t-statistics in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

This study uses innovation efficiency 1 (InnoEff1) as the dependent variable. However, InnoEff1 is replaced by three different types of corporate innovation efficiencies based on patent weights and types: innovation efficiency 2 (InnoEff2), innovation efficiency 3 (InnoEff3), and innovation efficiency 4 (InnoEff4). Table 4 illustrates the baseline regression analysis results of the impact of digital finance (DF) on these three innovation efficiencies. From Columns (1) to (3) of Table 4, it can be seen that the regression coefficients of digital finance (DF) on the alternative innovation efficiency variables are all positive and significant at the 1% level. Specifically, the regression coefficient of digital finance on innovation efficiency 2

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(InnoEff2) is 0.096, on innovation efficiency 3 (InnoEff3) is 0.05, and on innovation efficiency 4 (InnoEff4) is 0.069. This indicates that even when replacing the patent types, the result that digital finance can improve corporate innovation efficiency remains unchanged, consistent with the conclusions previously drawn.

### 4.3.2. Lagged Dependent Variable

To account for endogeneity, this study lags the dependent variable. The results are shown in Table 5. Column (1) illustrates the results when corporate innovation efficiency is lagged by one period, and Column (2) illustrates the results when it is lagged by two periods. From Columns (1) and (2) in Table 5, it is evident that the regression coefficients of digital finance on corporate innovation efficiency are positive and significant at the 1% level. Specifically, when innovation efficiency is lagged by one period, the regression coefficient of digital finance on innovation efficiency is 0.09; when innovation efficiency is lagged by two periods, the regression coefficient of digital finance on innovation efficiency is also 0.09. This implies that even after lagging in innovation efficiency, digital finance still has a significant positive impact on innovation efficiency, confirming the previous hypothesis and demonstrating the robustness of the research results.

**Table 5.** Baseline Regression Analysis Results for Lagged Dependent Variables

| | (1) | (2) | (3) |
|---|---|---|---|
| Variable | InnoEff1_lag | InnoEff1_lag2 | InnoEff4 |
| DF | 0.090*** | 0.090*** | 0.069*** |
| | (4.98) | (4.34) | (3.73) |
| Age | -0.001*** | -0.000** | -0.000** |
| | (-5.35) | (-2.50) | (-2.09) |
| Cash | 0.006 | 0.010 | 0.007 |
| | (0.60) | (0.82) | (0.62) |
| Lev | -0.000 | 0.007 | 0.016*** |
| | (-0.04) | (1.40) | (3.72) |
| Top1 | -0.000*** | -0.000*** | 0.000 |
| | (-3.01) | (-3.92) | (0.46) |
| Size | 0.030*** | 0.028*** | 0.023*** |
| | (44.12) | (36.65) | (32.05) |
| SOE | 0.008*** | 0.007*** | 0.003* |
| | (4.84) | (3.53) | (1.82) |
| lnGDP | -0.020*** | -0.018*** | -0.020*** |
| | (-4.48) | (-3.65) | (-4.46) |
| Growth | -0.006*** | -0.005*** | -0.000 |
| | (-4.97) | (-4.12) | (-0.36) |
| Constant | -0.836*** | -0.837*** | -0.583*** |
| | (-12.92) | (-11.09) | (-9.14) |
| Observations | 10,617 | 8,316 | 8,771 |
| R-squared | 0.389 | 0.347 | 0.406 |
| adj_R2 | 0.340 | 0.340 | 0.340 |
| F | 50.18 | 50.18 | 50.18 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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### 4.3.3. Instrumental Variable

To control for potential endogeneity issues, this study also employs the instrumental variable (IV) method for robustness checks. The average digital finance index by province is used as the instrumental variable for the explanatory variable. Table 6 shows that after including the instrumental variable, there are no issues of over-identification or weak instruments, indicating the appropriateness of the selected instrumental variable. Column (1) demonstrates the first-stage regression results where the dependent variable is the endogenous explanatory variable (DF), and the independent variables include the instrumental variable and other control variables. The regression coefficient of the instrumental variable is significantly positive, validating that the instrumental variable is positively correlated with the endogenous explanatory variable, the digital finance index. Column (2) presents the second-stage regression results. The coefficient of DF is significantly positive, indicating that after controlling for endogeneity, digital finance still significantly promotes corporate innovation efficiency. As a result, the research conclusions of this study are reliable and convincing, confirming the robustness of the previous results.

**Table 6.** Baseline Regression Analysis Results Using Instrumental Variables

| | (1) | (2) |
|---|---|---|
| | Ols | stage2 |
| Variable | DF | InnoEff1 |
| DF_mean | 0.087*** | |
| | (4.73) | |
| DF | | 0.111*** |
| | | (5.59) |
| Age | -0.001*** | -0.001*** |
| | (-5.08) | (-5.16) |
| Cash | 0.007 | 0.006 |
| | (0.56) | (0.51) |
| Lev | -0.002 | -0.002 |
| | (-0.43) | (-0.43) |
| Top1 | -0.000*** | -0.000*** |
| | (-2.75) | (-2.91) |
| Size | 0.030*** | 0.030*** |
| | (43.15) | (42.51) |
| SOE | 0.009*** | 0.009*** |
| | (4.80) | (4.83) |
| lnGDP | -0.020*** | -0.025*** |
| | (-4.47) | (-5.31) |
| Growth | -0.001 | -0.001 |
| | (-0.41) | (-0.44) |
| Constant | -0.818*** | -0.901*** |
| | (-12.92) | (-13.08) |
| Observations | 9,707 | 9,707 |
| R-squared | 0.394 | 0.395 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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# 5. Mechanism Analysis

## 5.1. Mechanism Analysis based on Corporate Financing Constraints

**Table 7.** Mechanism Test Results Based on Corporate Financing Constraints

| | (1) | (2) | (3) |
|---|---|---|---|
| Variable | InnoEff1 | KZ | InnoEff1 |
| DF | 0.087*** | -1.163*** | 0.089*** |
| | (4.67) | (-3.83) | (4.74) |
| KZ | | | -0.001* |
| | | | (-1.68) |
| Age | -0.001*** | 0.022*** | -0.001*** |
| | (-5.14) | (12.53) | (-5.04) |
| Cash | 0.007 | -17.340*** | -0.007 |
| | (0.59) | (-101.64) | (-0.50) |
| Lev | -0.002 | 7.094*** | 0.004 |
| | (-0.44) | (105.08) | (0.76) |
| Top1 | -0.000*** | -0.011*** | -0.000*** |
| | (-2.92) | (-13.93) | (-3.16) |
| Size | 0.030*** | -0.297*** | 0.030*** |
| | (42.49) | (-27.84) | (41.06) |
| SOE | 0.009*** | 0.034 | 0.009*** |
| | (4.73) | (1.21) | (4.69) |
| lnGDP | -0.020*** | 0.267*** | -0.021*** |
| | (-4.45) | (3.65) | (-4.51) |
| Growth | -0.001 | -0.145*** | -0.001 |
| | (-0.45) | (-8.53) | (-0.69) |
| Constant | -0.818*** | 9.583*** | -0.818*** |
| | (-12.76) | (9.11) | (-12.71) |
| Observations | 9,707 | 14,123 | 9,633 |
| R-squared | 0.394 | 0.707 | 0.395 |
| adj_R2 | 0.389 | 0.389 | 0.389 |
| F | 69.95 | 69.95 | 69.95 |

t-statistics in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

This section examines the mediating role of corporate financing constraints in the relationship between digital finance and corporate innovation efficiency. The results are presented in Table 7. From Column (1) of Table 7, it can be observed that the regression coefficient of digital finance on corporate innovation efficiency is 0.087, which is significant at the 1% level. This clarifies that digital finance significantly enhances corporate innovation efficiency. In Column (2), the regression coefficient of digital finance on corporate financing constraints is -1.163, which is also significant at the 1% level, suggesting that higher levels of digital finance development help alleviate corporate financing constraints. Furthermore, the regression coefficient of financing constraints on corporate innovation efficiency is -0.001, significant at the 10% level, identifying that financing constraints have a suppressive effect on innovation efficiency. Column (3) illustrates that after adding the financing constraints variable, the regression coefficient of digital finance on corporate innovation efficiency (0.089) remains significant and even increases marginally. This demonstrates that financing constraints play a

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mediating role in the process of digital finance enhancing corporate innovation efficiency. Digital finance indirectly improves corporate innovation efficiency by alleviating financing constraints, thus validating Hypothesis H2.

## 5.2. Mechanism Analysis based on Corporate Financial Distress

**Table 8.** Mechanism Test Results Based on Corporate Financial Distress

| | (1) | (2) | (3) |
|---|---|---|---|
| Variable | InnoEff1 | Zsore | InnoEff1 |
| DF | 0.087*** | -1.741* | 0.088*** |
| | (4.67) | (-1.82) | (4.73) |
| Zsore | | | -0.001*** |
| | | | (-3.49) |
| Age | -0.001*** | 0.021*** | -0.001*** |
| | (-5.14) | (3.83) | (-5.14) |
| Cash | 0.007 | 7.803*** | 0.015 |
| | (0.59) | (14.52) | (1.30) |
| Lev | -0.002 | -15.085*** | -0.011** |
| | (-0.44) | (-70.96) | (-2.18) |
| Top1 | -0.000*** | 0.008*** | -0.000*** |
| | (-2.92) | (3.16) | (-2.88) |
| Size | 0.030*** | -0.364*** | 0.030*** |
| | (42.49) | (-10.82) | (41.99) |
| SOE | 0.009*** | 0.052 | 0.009*** |
| | (4.73) | (0.59) | (4.91) |
| lnGDP | -0.020*** | 0.399* | -0.021*** |
| | (-4.45) | (1.73) | (-4.49) |
| Growth | -0.001 | 0.114** | -0.001 |
| | (-0.45) | (2.13) | (-0.50) |
| Constant | -0.818*** | 26.057*** | -0.811*** |
| | (-12.76) | (7.86) | (-12.62) |
| Observations | 9,707 | 14,172 | 9,675 |
| R-squared | 0.394 | 0.434 | 0.395 |
| adj_R2 | 0.389 | 0.389 | 0.389 |
| F | 70.27 | 70.27 | 70.27 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

This section examines the mediating role of corporate financial distress in the relationship between digital finance and corporate innovation efficiency. The results are presented in Table 8. From Column (1) of Table 8, it is evident that digital finance significantly enhances corporate innovation efficiency. In Column (2), the regression coefficient of digital finance on financial distress is -1.741, which is significant at the 10% level. A possible explanation might be that digital finance has a negative impact on corporate financial distress, implying that higher levels of digital finance development help alleviate financial distress. Furthermore, the regression coefficient of financial distress on corporate innovation efficiency is -0.001, which is significant at the 1% level, indicating that financial distress negatively affects innovation efficiency. Column (3) illustrates the impact of corporate financial distress on the relationship between digital finance and corporate innovation efficiency with a regression coefficient of 0.088 and

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significant at the 1% level, which is higher than the coefficient in Column (1). This confirms the mediating effect of corporate financial distress. These results demonstrate that digital finance indirectly promotes corporate innovation efficiency by alleviating financial distress, thus validating Hypothesis H3.

# 6. Heterogeneity Test

## 6.1. Sub-sample Study based on Ownership Nature

State-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) differ in terms of financing constraints. Therefore, this study conducts a heterogeneity test based on the ownership nature of enterprises. The results are presented in Table 9. From Column (1) of Table 9, it can be seen that in state-owned enterprises, the regression coefficient of digital finance on corporate innovation efficiency is 0.074, which is significant at the 5% level. In Column (2), for non-state-owned enterprises, the regression coefficient of digital finance on corporate innovation efficiency is 0.080, which is significant at the 1% level. This indicates that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in non-state-owned enterprises. One possible implication of this finding is that state-owned enterprises often receive policy support and guarantees from the government, which may reduce their motivation to innovate. In contrast, non-state-owned enterprises must rely on their own capabilities and technologies to gain a competitive edge in the market, thus exhibiting higher innovation incentives. Therefore, digital finance can more effectively enhance innovation efficiency in non-state-owned enterprises.

**Table 9.** Heterogeneity Regression Results Based on Ownership Nature

| | (1) | (2) |
|---|---|---|
| Variable | InnoEff1 | InnoEff1 |
| DF | 0.074** | 0.080*** |
| | (2.00) | (3.70) |
| Age | -0.000 | -0.001*** |
| | (-1.00) | (-5.01) |
| Cash | 0.008 | 0.006 |
| | (0.38) | (0.43) |
| Lev | -0.028*** | 0.010* |
| | (-3.61) | (1.80) |
| Top1 | -0.000*** | -0.000** |
| | (-3.17) | (-2.41) |
| Size | 0.032*** | 0.029*** |
| | (28.30) | (30.63) |
| lnGDP | -0.011 | -0.024*** |
| | (-1.25) | (-4.49) |
| Growth | 0.001 | -0.002 |
| | (0.74) | (-1.29) |
| Constant | -0.884*** | -0.699*** |
| | (-7.28) | (-9.03) |
| Observations | 3,106 | 6,601 |
| R-squared | 0.484 | 0.362 |
| adj_R2 | 0.354 | 0.354 |
| F | 46.28 | 46.28 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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## 6.2. Sub-sample Study based on Enterprise Size

This study divides enterprises based on the 25% quantile of enterprise size, with the top 25% representing large-scale enterprises and the remaining 75% representing small and medium-sized enterprises (SMEs). The heterogeneity regression results based on enterprise size are shown in Table 10. From Column (1) of Table 10, it can be observed that in large enterprises, the regression coefficient of digital finance on corporate innovation efficiency is 0.031, which is insignificant. Column (2) illustrates that in small and medium-sized enterprises, the regression coefficient of digital finance on corporate innovation efficiency is 0.097, which is significant at the 1% level. This indicates that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in SMEs. The possible reason for this finding is that conventional financial markets favor large-scale enterprises. At the same time, SMEs face financial discrimination, making it difficult for them to obtain innovation funding in conventional financial markets. Digital finance provides SMEs with better support for innovation by expanding access to financial resources. Therefore, digital finance can significantly enhance innovation efficiency in SMEs.

**Table 10.** Heterogeneity Regression Results Based on Enterprise Size

| | (1) | (2) |
|---|---|---|
| Variable | InnoEff1 | InnoEff1 |
| DF | 0.031 | 0.097*** |
| | (0.78) | (4.52) |
| Age | -0.000 | -0.001*** |
| | (-0.39) | (-5.35) |
| Cash | -0.008 | 0.013 |
| | (-0.30) | (1.06) |
| Lev | -0.016 | 0.003 |
| | (-1.55) | (0.72) |
| Top1 | -0.000* | -0.000** |
| | (-1.75) | (-2.37) |
| Size | 0.032*** | 0.032*** |
| | (18.47) | (29.35) |
| SOE | 0.011*** | 0.008*** |
| | (3.09) | (3.56) |
| lnGDP | 0.003 | -0.026*** |
| | (0.31) | (-4.91) |
| Growth | -0.002 | 0.000 |
| | (-0.70) | (0.25) |
| Constant | -0.789*** | -0.859*** |
| | (-5.76) | (-11.22) |
| Observations | 2,278 | 7,429 |
| R-squared | 0.470 | 0.341 |
| adj_R2 | 0.333 | 0.333 |
| F | 43.09 | 43.09 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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## 6.3. Sub-sample Study based on Regions

The economic development levels of China's eastern and central-western regions vary significantly. Therefore, this study conducts a heterogeneity test based on regions. The results are presented in Table 11. From Column (1) of Table 11, it is observed that in the economically developed eastern region, the regression coefficient of digital finance on corporate innovation efficiency is 0.029, which is insignificant. Column (2) shows that in the less economically developed non-eastern regions, the regression coefficient of digital finance on corporate innovation efficiency is 0.279, which is significant at the 1% level. This reveals that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in the central and western regions. It is widely accepted that developing digital finance in less economically developed regions can more easily mobilize funds, which enterprises can utilize for innovation. Therefore, digital finance is more effective in enhancing corporate innovation efficiency in the central and western regions.

**Table 11.** Heterogeneity Regression Results Based on Regions

| | (1) | (2) |
|---|---|---|
| Variable | InnoEff1 | InnoEff1 |
| DF | 0.029 | 0.279*** |
| | (1.30) | (6.90) |
| Age | -0.001*** | -0.001*** |
| | (-3.86) | (-3.07) |
| Cash | 0.012 | 0.000 |
| | (0.92) | (0.00) |
| Lev | 0.001 | -0.002 |
| | (0.13) | (-0.28) |
| Top1 | -0.000** | -0.000** |
| | (-1.97) | (-1.98) |
| Size | 0.030*** | 0.030*** |
| | (35.28) | (22.17) |
| SOE | 0.011*** | 0.003 |
| | (4.51) | (0.99) |
| lnGDP | -0.015*** | -0.016 |
| | (-2.90) | (-1.50) |
| Growth | -0.002 | 0.001 |
| | (-1.12) | (0.35) |
| Constant | -0.516*** | -1.922*** |
| | (-6.07) | (-11.70) |
| Observations | 6,787 | 2,920 |
| R-squared | 0.409 | 0.412 |
| adj_R2 | 0.396 | 0.396 |
| F | 25.23 | 25.23 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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## 6.4. Sub-sample Study based on City Classification

Due to differences in city size and international influence between first-tier and non-first-tier cities in China, this study conducts a heterogeneity test based on city classification. The results are presented in Table 12. Column (1) of Table 12 shows that in first-tier cities, the regression coefficient of digital finance on corporate innovation efficiency is 0.027, which is insignificant. Column (2) presents that in non-first-tier cities, the regression coefficient of digital finance on corporate innovation efficiency is 0.088, which is significant at the 1% level. This implies that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in non-first-tier cities. A possible explanation might be that business operations in first-tier cities may have already reached a saturation point. Meanwhile, there is more room for growth in non-first-tier cities. As a result, enterprises in non-first-tier cities can more easily attract talent and resources through the development of digital finance, further enhancing corporate innovation efficiency.

**Table 12.** Heterogeneity Regression Results Based on City Classification

| | (1) | (2) |
|---|---|---|
| Variable | InnoEff1 | InnoEff1 |
| DF | 0.027 | 0.088*** |
| | (0.26) | (4.53) |
| Age | -0.001*** | -0.000*** |
| | (-2.80) | (-3.53) |
| Cash | 0.014 | 0.012 |
| | (0.59) | (0.98) |
| Lev | -0.004 | -0.001 |
| | (-0.41) | (-0.19) |
| Top1 | -0.000*** | -0.000** |
| | (-3.28) | (-2.11) |
| Size | 0.032*** | 0.029*** |
| | (22.27) | (34.91) |
| SOE | 0.015*** | 0.009*** |
| | (3.55) | (4.18) |
| lnGDP | -0.024 | -0.012** |
| | (-1.15) | (-2.41) |
| Growth | -0.003 | 0.001 |
| | (-1.26) | (0.53) |
| Constant | -0.461 | -0.889*** |
| | (-1.21) | (-12.66) |
| Observations | 2,303 | 7,404 |
| R-squared | 0.500 | 0.378 |
| adj_R2 | 0.371 | 0.371 |
| F | 52.31 | 52.31 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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## 6.5. Marketization Level

This study groups industries based on the median marketization level to conduct a heterogeneity test. The results are presented in Table 13. Column (1) of Table 13 shows that in industries with a high level of marketization, the regression coefficient of digital finance on corporate innovation efficiency is 0.021, which is insignificant. Column (2) illustrates that in industries with a low level of marketization, the regression coefficient of digital finance on corporate innovation efficiency is 0.181, which is significant at the 1% level. This indicates that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in industries with a lower level of marketization. It could be the case that in highly marketized industries, the homogeneity among enterprises is more pronounced, which is not conducive to innovation. Conversely, in less marketized industries, there are greater differences in the operations of enterprises. Digital finance boosts innovation efficiency in these industries by enhancing competitiveness.

**Table 13.** Heterogeneity Regression Results Based on Marketization Level

| | (1) | (2) |
|---|---|---|
| Variable | InnoEff1 | InnoEff1 |
| DF | 0.021 | 0.181*** |
| | (0.71) | (5.21) |
| Age | -0.001*** | -0.001*** |
| | (-4.00) | (-3.32) |
| Cash | 0.002 | 0.018 |
| | (0.11) | (1.17) |
| Lev | 0.005 | -0.005 |
| | (0.77) | (-0.87) |
| Top1 | -0.000** | -0.000** |
| | (-2.13) | (-1.98) |
| Size | 0.030*** | 0.030*** |
| | (30.11) | (29.44) |
| SOE | 0.010*** | 0.007*** |
| | (3.62) | (2.95) |
| lnGDP | -0.016** | -0.039*** |
| | (-2.25) | (-5.27) |
| Growth | -0.002 | 0.001 |
| | (-1.08) | (0.47) |
| Constant | -0.510*** | -1.120*** |
| | (-4.52) | (-8.94) |
| Observations | 4,591 | 5,116 |
| R-squared | 0.432 | 0.385 |
| adj_R2 | 0.375 | 0.375 |
| F | 36.65 | 36.65 |

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

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# 7. Conclusion and Policy Recommendations

## 7.1. Conclusion

In the complex current global economic landscape, corporate innovation plays a crucial role in shaping a country's international competitiveness and ensuring the sustainable competitive advantage of enterprises. It is also a key guarantee for high-quality economic development in China. In this era of rapid digital technology development, the integration of digital technology with finance has given rise to digital finance, which has an inherent connection with corporate innovation. Existing literature extensively explores the impact of digital finance on corporate innovation investment, output, and green innovation. However, there is a paucity of research on the efficiency of corporate innovation, and there are conflicting views on whether digital finance promotes or hinders this efficiency. This study investigates the impact of digital finance on corporate innovation efficiency using bidirectional fixed effects models and mediation effect models. The conclusions of the study are as follows:

Digital finance significantly enhances corporate innovation efficiency. This finding remains robust across various robustness checks, including the substitution and lagging of the dependent variable, and the inclusion of instrumental variables.

Further analysis reveals that digital finance promotes corporate innovation efficiency by alleviating financing constraints and financial distress. Both financing constraints and financial distress act as mediating factors in improving corporate innovation.

The heterogeneity tests show that the promoting effect of digital finance on corporate innovation efficiency is more pronounced in non-state-owned enterprises, small and medium-sized enterprises, enterprises in central and western regions, enterprises in non-first-tier cities, and enterprises in regions with lower marketization levels.

These findings underscore the critical role of digital finance in enhancing corporate innovation efficiency, especially in contexts where traditional financial support may be insufficient or unevenly distributed. The results suggest tailored policy approaches to leverage digital finance for fostering innovation in various types of enterprises and regions.

## 7.2. Policy Recommendation

After the above research and analysis, this article proposes the following policy recommendations for the development of digital finance and enterprise innovation:

(1) At the enterprise level, various departments should be encouraged to apply digital finance to their daily work, rely on big data to accurately analyze user needs, achieve information storage and matching, improve enterprise management and service efficiency, and reduce service costs for enterprises. Enterprises should also enhance the coverage area of services, expand financing channels, and provide stable and sufficient financial support for enterprise innovation. At the same time, enterprises should stimulate employees' willingness to innovate and cultivate their independent innovation ability.

(2) At the industry level, the financial regulatory system should provide financial support to enterprises with high demand for funds and strong innovation capabilities based on improving themselves. Regulatory authorities should promote the equalization of financial resource allocation, monitor and evaluate the risks of digital finance operating in the market, and balance the relationship between financial risks and the innovative development of the real economy. At the same time, regulatory authorities should also formulate and implement sustained and focused policies to avoid policy conflicts and stabilize market policy predictions.

(3) At the government level, when formulating digital finance policies, full consideration should be given to the characteristics of enterprises, such as the nature of enterprise property rights, enterprise scale, the city and region where the enterprise is located, and the market

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environment in which it operates. The government can pay more attention to non-state-owned enterprises and small and medium-sized enterprises located in the central and western regions, non-first-tier cities, and low levels of marketization. These enterprises have greater innovation space and strong innovation enthusiasm; The government should also formulate multi-level policies to meet the diverse needs of different business groups.

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