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IMPACT OF DIGITAL FINANCE ON CORPORATE SUSTAINABILITY

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Abstract This study investigates the impact of digital finance on corporate sustainable development using panel data from Chinese A-share listed firms between 2011 and 2022. By constructing a multi-dimensional digital finance index and employing fixed-effect and instrumental variable regression models, the analysis reveals that digital finance significantly promotes firms' sustainable growth. Among the sub-dimensions, the depth of use exerts the strongest effect. Further, total factor productivity mediates the relationship between digital finance and sustainability, while financial risk also plays a partial mediating role. Heterogeneity analysis indicates that the positive impact of digital finance is more pronounced in private enterprises, medium-sized firms, service industries, and western regions. These findings underscore the vital role of digital financial infrastructure in enhancing corporate sustainability and suggest that targeted financial innovation policies can foster more inclusive and balanced economic development. The study contributes to the literature by clarifying the mechanisms and boundary conditions through which digital finance affects sustainable business transformation.

Keywords: Digital finance, Corporate sustainable development, Total factor productivity, Financial risk, Instrumental variable regression, Enterprise heterogeneity, Sustainability mechanism, Listed firms in China, Depth of use, Regional disparity

1.Introduction

In recent years, digital finance has emerged as a transformative force in the global financial landscape, driven by rapid advancements in big data, blockchain, and mobile technology. In China, where economic recovery and sustainability are pressing national priorities, digital finance offers new pathways for corporate development (Li et al., 2022). As enterprises seek to enhance resilience and long-term value creation, the integration of digital technologies into financial services presents opportunities to address persistent challenges such as limited financial access, inefficiencies in resource allocation, and exposure to financial risks (Hokmabadi et al., 2024).

China's policy orientation has increasingly emphasized the role of digital finance in revitalizing the real economy. Government initiatives, such as the Financial Technology Development Plan (2022–2025), underline the strategic importance of leveraging financial innovation to support inclusive growth and environmental sustainability (Chen & Xing, 2025; Dong et al., 2025). However, while the macroeconomic benefits of digital finance have been well documented, its micro-level impacts—especially on corporate

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sustainability—remain underexplored (Niu et al., 2025).

This study investigates how digital finance contributes to corporate sustainability by improving total factor productivity, reducing financial risk, and enabling more efficient capital allocation. Using panel data from Chinese listed firms between 2011 and 2022, this research employs a mixed-methods approach, combining regression analysis with case studies. It also examines heterogeneous effects across firm sizes, industries, and regions. By uncovering the mechanisms through which digital finance influences business sustainability, the study contributes new empirical evidence and theoretical insights to the fields of financial innovation and sustainable enterprise development.

2.Literature Review

2.1 Factors Influencing Corporate Sustainability

Corporate sustainability has evolved as a multidimensional construct encompassing economic viability, social responsibility, and environmental stewardship. Earlier studies have emphasized the importance of internal and external drivers of sustainability. Internally, managerial ability, entrepreneurship, and ESG performance have shown positive impacts on long-term business value creation (Li et al., 2025). Externally, regulatory environments, stakeholder expectations, and financial accessibility also shape sustainability outcomes. In particular, access to stable and affordable financing remains a foundational enabler of sustainable corporate practices (Baah et al., 2020; Cheung et al., 2022).

2.2 Functions and Economic Role of Digital Finance

Digital finance refers to the application of digital technologies—such as big data, cloud computing, blockchain, and mobile platforms—in financial services. It has been widely recognized for its role in expanding financial inclusion, lowering transaction costs, and improving capital allocation (Du et al., 2023; Song et al., 2021). Digital finance allows underserved populations, including SMEs and rural households, to access credit and payment systems. It enhances financial transparency and real-time risk assessment while reducing the information asymmetry inherent in traditional banking (Dashottar & Srivastava, 2021; Jin & Liu, 2025). On a macro level, digital finance has been linked to poverty reduction, economic resilience, and inclusive growth (Wang et al., 2023).

2.3 Digital Finance and Corporate Sustainability: Toward a New Framework

While digital finance's role in economic growth and financial access is well established, its micro-level impact on corporate sustainability remains underexplored. Recent research suggests that digital finance can enhance firms' productivity , reduce financial risk, and improve capital efficiency (Tang et al., 2022; Wu & Huang, 2022). However, most of these studies focus on isolated outcomes rather than offering a holistic explanation of how digital finance enables sustainable business models.

Moreover, few studies examine the mediating mechanisms—such as total factor productivity (TFP) improvements or financial risk reduction—through which digital finance contributes to sustainability. Even less attention has been paid to heterogeneity across firm size, industry, or region, particularly in the Chinese context where economic structures vary widely (Guo et al., 2022; Liu et al., 2023; Wei & Liu, 2022). Therefore, this study addresses a critical gap by integrating digital finance within the theoretical framework of financial development, financial exclusion, and sustainability theories to analyze its comprehensive impact on enterprise-level sustainability.

Thus, it leads to the following hypotheses:

H1: The better the development of digital finance, the more sustainable the business is, and digital finance promotes sustainable business development.

H2: The development of digital finance helps companies to increase their total factor productivity, which in turn contributes to their sustainable development.

H3: Digital finance significantly reduces corporate financial risk and thus promotes sustainable business development.

3.Research Method

This study adopts a quantitative research approach based on panel data from 5,041 A-share listed companies in China spanning from 2011 to 2022. The primary data sources include the Peking University Digital Financial Inclusion Index and the CSMAR database. The dependent variable, corporate sustainability, is measured through a composite index reflecting financial, social, and environmental performance. The core independent variable is digital finance, proxied by the provincial-level digital finance index, which captures the breadth of coverage, depth of use, and level of digitization. Two mediating variables—total factor productivity (TFP) and financial risk—are included to examine transmission mechanisms. TFP is calculated using the Levinsohn-Petrin method, while financial risk is measured by Z-scores and leverage ratios. Control variables such as firm size, age, ROA, and industry are added to ensure robustness.

This study employs fixed-effects panel regression models with robust standard errors. The analysis includes a baseline model assessing the direct effect of digital finance on corporate sustainability, followed by mediation models to evaluate the indirect effects through TFP and financial risk. Additional heterogeneity analyses are conducted to explore variations across firm size, industry type, and regional economic development levels. This quantitative design allows for a comprehensive assessment of the role of digital finance in fostering enterprise-level sustainability.

4. Results

Table 1 presents the descriptive statistics of all variables used in this study. The dependent variable, corporate sustainable development, is measured in two forms: SGR (mean = 0.298) and SGR_H (mean = 0.075), indicating moderate variability across firms. The key explanatory variable, digital finance (DFI), has an average value of 5.566, with sub-indices showing comparable means: breadth of coverage (DFW = 5.489), depth of use (DFP = 5.587), and degree of financialization (DFE = 5.707), reflecting relatively balanced regional development. The mediating variables—total factor productivity (TFP) and financial risk (FR)—have mean values of 8.35 and 1.427, respectively, suggesting considerable heterogeneity in production efficiency and financial stability among firms. Control variables include firm age (mean = 23.146 years), enterprise size (Size = 22.13), first shareholder's ownership (Fir = 34.66%), dual leadership (Dual = 30.6%), proportion of independent directors (Inde = 37.6%), and audit opinion (Aud = 0.981), indicating that most firms received unqualified audit opinions and maintain moderately independent governance structures. Overall, the data demonstrate sufficient variation to support robust regression analysis.

Table 1 Descriptive statistics of relevant variables (changed)

Variable type	variable name	notation	average value	(statistics) deviation	standard	minimum value	maximum values
explanatory variable	Sustainable development	SGR	0.298	0.378		-2.342	0.799

	Sustainable development	SGR_H	0.075	0.073	-0.03	0.434
explanatory variable	digital finance	DFI	5.566	0.544	3.487	6.129
	breadth of coverage	DFW	5.489	0.593	3.006	6.122
	Depth of use	DFP	5.587	0.509	3.799	6.192
	Degree of financialization	DFE	5.707	0.621	3.055	6.14
intermediary variable	Total factor productivity	TFP	8.35	1.045	6.181	11.164
	financial risk	FR	1.427	0.675	-0.369	3.441
control variable	Age of business	Age	23.146	5.977	5	72
	Enterprise size	Size	22.13	1.429	19.086	26.528
	Percentage of first shareholder	Fir	0.34662	0.1506218	0.002863	0.89991
	two jobs in one	Dual	0.306	0.461	0	1
	Proportion of independent directors	Inde	0.376	0.055	0	0.8
	Audit opinion	Aud	0.981	0.136	0	1

Table 2 displays the correlation matrix among the study variables. The dependent variable, sustainable development (SGR), shows a positive correlation with digital finance (DFI = 0.0932), especially with its sub-dimensions—depth of use (DFP = 0.101) and breadth of coverage (DFW = 0.0944)—indicating that higher levels of digital financial development are modestly associated with improved corporate sustainability (Li et al., 2022). SGR is also positively correlated with total factor productivity (TFP = 0.215) and financial risk (FR = 0.461), suggesting that productivity improvements and risk levels may influence sustainable outcomes. Control variables such as firm size (Size = 0.172), dual leadership (Dual = 0.156), and proportion of independent directors (Inde = 0.275) also exhibit meaningful positive correlations with SGR, highlighting potential governance-related influences. Notably, DFI and its sub-indices are highly correlated with each other (e.g., DFI–DFW = 0.991), which warrants caution regarding potential multicollinearity in regression analysis. The correlations align with theoretical expectations and provide preliminary support for the hypothesized relationships between digital finance, mediating factors, and sustainable development.

Table 2 Descriptive statistics of variables

	SGR	DFI	DFW	DFP	DFE	TFP	FR	Age	Size	Fir	Dual	Inde	Aud
SGR	1												
DFI	0.0932	1											

DFW	0.0944	0.991	1									
DFP	0.101	0.975	0.956	1								
DFE	0.0664	0.911	0.865	0.855	1							
TFP	0.215	0.134	0.139	0.137	0.0945	1						
FR	0.461	0.0497	0.0534	0.0727	0.0004	0.276	1					
Age	-0.0235	0.307	0.305	0.295	0.287	0.175	-0.0932	1				
Size	0.172	0.0867	0.0894	0.0724	0.0847	0.795	-0.162	0.236	1			
Fir	-0.0114	0.0544	0.0545	0.0529	0.0492	0.0178	-0.0079	-0.0119	0.0167	1		
Dual	0.156	-0.0591	-0.0542	-0.0604	-0.0628	0.173	0.0969	-0.0817	0.168	0.0505	1	
Inde	0.275	0.0193	0.0207	0.0224	0.0063	0.0677	0.13	-0.0436	0.0671	0.001	0.0665	1
Aud	0.0006	0.0848	0.0863	0.0959	0.054	-0.139	0.0783	-0.111	-0.205	0.108	-0.0518	0.0063	1

Table 3 presents the results of a series of stepwise regressions assessing the impact of digital finance (DFI) on corporate sustainable development (SGR). Across all model specifications (1) to (7), DFI consistently shows a significant positive effect on SGR, with coefficients ranging from 0.063 to 0.075 and all t-values exceeding 16, indicating robust statistical significance at the 1% level. As additional control variables are introduced, the model fit improves substantially, with adjusted R^2 increasing from 0.009 in the baseline model to 0.127 in the fully specified model. Firm age (Age) negatively influences sustainability, suggesting that older firms may face structural rigidities (Collevecchio et al., 2025). Firm size (Size), ownership concentration (Fir), and dual leadership roles (Dual) all positively impact SGR, while the proportion of independent directors (Inde) shows a significant negative association, possibly reflecting limited board influence on strategic sustainability goals. Audit opinion (Aud) exhibits a strong positive effect, implying that firms with cleaner audits tend to perform better in sustainability terms.

Table 3 Table of regression results (2011-2022)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
variant	SGR	SGR	SGR	SGR	SGR	SGR	SGR
DFI	0.063***	0.075***	0.072***	0.069***	0.068***	0.069***	0.063***
	(17.07)	(18.74)	(18.86)	(17.90)	(17.40)	(17.65)	(16.70)
Age		-0.003***	-0.006***	-0.005***	-0.005***	-0.005***	-0.004***
		(-9.45)	(-14.66)	(-12.42)	(-11.56)	(-11.68)	(-9.81)
Size			0.047***	0.048***	0.048***	0.048***	0.044***
			(26.30)	(25.16)	(24.90)	(24.98)	(24.74)
Fir				0.003***	0.003***	0.003***	0.003***
				(25.29)	(24.73)	(24.93)	(23.55)
Dual					0.021***	0.024***	0.021***
					(4.98)	(5.49)	(5.08)
Inde						-0.186***	-0.178***
						(-5.18)	(-5.13)
Aud							0.695***
							(16.36)
_cons	-0.046**	-0.050**	-1.030***	-1.154***	-1.166***	-1.107***	-1.664***
	(-2.23)	(-2.42)	(-22.59)	(-23.95)	(-23.78)	(-22.48)	(-25.91)
N	34958	34958	34958	33865	33103	33103	33103
r2	0.009	0.012	0.046	0.067	0.067	0.067	0.128
r2_a	0.009	0.012	0.046	0.066	0.067	0.067	0.127
F	291.414	178.064	298.518	321.263	249.266	208.859	204.303

Table 4 reports the robustness test results by comparing regression outcomes using two different time frames: full data from 2011–2022 and a restricted sample from 2011–2020. In both models, digital finance (DFI) maintains a statistically significant and positive impact on corporate sustainable development (SGR), with coefficients of 0.063 and 0.062, respectively, and strong t-values above 14. The signs and significance levels of control variables remain consistent across the two samples: firm age negatively affects sustainability, while firm size, ownership concentration (Fir), dual leadership (Dual), and audit opinion (Aud) are positively associated with SGR. The proportion of independent directors (Inde) continues to show a significant negative effect. The adjusted R^2 improves slightly in the shorter time frame (from 0.127 to 0.140), indicating that the model's explanatory power remains stable and even slightly stronger when excluding the later years. These results confirm the robustness and reliability of the main findings, demonstrating that the positive role of digital finance in promoting enterprise sustainability is not driven by temporal sample variations.

Table 4 Table of regression results of digital finance on corporate sustainability

	Data 2011-2022	Data for 2011-2020
	(1) SGR	(2) SGR
DFI	0.063***	0.062***

	(16.70)	(14.77)
Age	-0.004***	-0.004***
	(-9.81)	(-10.09)
Size	0.044***	0.044***
	(24.74)	(21.81)
Fir	0.003***	0.003***
	(23.55)	(19.98)
Dual	0.021***	0.020***
	(5.08)	(4.19)
Inde	-0.178***	-0.199***
	(-5.13)	(-5.02)
Aud	0.695***	0.706***
	(16.36)	(15.40)
_cons	-1.664***	-1.659***
	(-25.91)	(-23.11)
N	33103	25443
r2	0.128	0.141
r2_a	0.127	0.140
F	204.303	155.813

Table 5 presents regression results using an alternative dependent variable, SGR_H, to test the robustness of the main findings. Across all model specifications (1) to (7), digital finance (DFI) remains positively and significantly associated with high-quality sustainable growth, with coefficients consistently at 0.011 and t-values above 8, reaffirming the positive effect of digital finance. However, the explanatory power of the models is limited, as indicated by the low R^2 (0.004) and negative adjusted R^2 values, suggesting that SGR_H may capture a more nuanced or restrictive aspect of sustainability. Control variables show mixed results: firm age has a consistently negative and significant impact, while firm size becomes insignificant, and ownership concentration (Fir) negatively affects SGR_H. Variables such as dual leadership (Dual), independent directors (Inde), and audit opinion (Aud) are statistically insignificant in this specification. Despite the weaker model fit, the robustness of the digital finance variable across alternative measures of sustainability supports the credibility of the study's central claim: digital finance plays a consistent and positive role in promoting enterprise sustainability.

Table 4 Regression analysis with replacement of explanatory variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	SGR_H	SGR_H	SGR_H	SGR_H	SGR_H	SGR_H	SGR_H
DFI	0.007***	0.009***	0.009***	0.011***	0.011***	0.011***	0.011***
	(10.46)	(6.84)	(6.64)	(8.61)	(8.41)	(8.42)	(8.42)
Age		-0.006*	-0.008**	-0.017***	-0.017***	-0.017***	-0.017***
		(-1.68)	(-2.08)	(-4.47)	(-4.40)	(-4.38)	(-4.39)
Size			0.001	0.000	0.000	0.000	0.000

			(1.46)	(0.46)	(0.47)	(0.46)	(0.49)
Fir				-0.019***	-0.021***	-0.021***	-0.021***
				(-3.17)	(-3.45)	(-3.44)	(-3.42)
Dual					0.001	0.001	0.001
					(0.61)	(0.65)	(0.65)
Inde						-0.007	-0.007
						(-0.69)	(-0.69)
Aud							-0.001
							(-0.43)
_cons	-0.116***	-0.110***	-0.130***	-0.090***	-0.089***	-0.086***	-0.085***
	(-29.98)	(-20.92)	(-8.87)	(-5.97)	(-5.84)	(-5.49)	(-5.40)
N	34958	34958	34958	33865	33103	33103	33103
r2	0.004	0.004	0.004	0.004	0.004	0.004	0.004
r2_a	-0.164	-0.164	-0.164	-0.168	-0.172	-0.172	-0.172
F	109.396	56.109	38.116	31.844	24.842	20.780	17.838

Table 6 reports the regression results from a sub-sample analysis, reaffirming the positive impact of digital finance (DFI) on corporate sustainable development (SGR). Across all seven model specifications, DFI remains significantly positive, with coefficients ranging from 0.061 to 0.077 and strong t-values above 15, indicating high statistical significance. The inclusion of firm-level control variables improves the model's explanatory power, as reflected in the adjusted R^2 increasing from 0.009 in the baseline model to 0.128 in the fully specified model. Firm age consistently shows a negative impact on SGR, while firm size, ownership concentration (Fir), and dual leadership (Dual) have positive effects. Interestingly, the proportion of independent directors (Inde) shows a significant negative relationship with SGR in the later models, and audit opinion (Aud) maintains a strong positive influence. The results support the robustness of the main conclusion: digital finance contributes meaningfully to improving corporate sustainability, even when tested on different sub-samples.

Table 5 Regression analysis of deleted anomalies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	SGR	SGR	SGR	SGR	SGR	SGR	SGR
DFI	0.061***	0.076***	0.077***	0.072***	0.071***	0.072***	0.067***
	(15.21)	(17.16)	(17.98)	(16.81)	(16.36)	(16.49)	(15.74)
Age		-0.004***	-0.007***	-0.006***	-0.006***	-0.006***	-0.005***
		(-9.48)	(-14.67)	(-13.16)	(-12.19)	(-12.19)	(-10.65)
Size			0.055***	0.059***	0.059***	0.059***	0.054***
			(23.26)	(23.47)	(23.25)	(23.24)	(22.83)
Fir				0.003***	0.003***	0.003***	0.003***
				(21.98)	(21.53)	(21.63)	(20.45)
Dual					0.024***	0.025***	0.023***
					(4.74)	(4.98)	(4.80)

Inde						-0.116***	-0.126***
						(-2.70)	(-3.01)
Aud							0.651***
							(14.05)
_cons	-0.040*	-0.044*	-1.202***	-1.407***	-1.405***	-1.364***	-1.862***
	(-1.77)	(-1.92)	(-20.85)	(-22.66)	(-22.49)	(-21.45)	(-23.90)
N	26199	26199	26199	25305	24788	24788	24788
r2	0.009	0.013	0.051	0.074	0.074	0.075	0.129
r2_a	0.009	0.013	0.051	0.074	0.074	0.074	0.128
F	231.363	151.037	240.397	247.970	194.673	162.713	155.388

Table 7 shows the instrumental variable (IV) regression results using one-period and two-period lagged values of digital finance (DFI) as instruments to address potential endogeneity concerns. Columns (1) and (3) confirm the strong relevance of the lagged DFI instruments, with first-stage coefficients of 0.665 and 1.000, and extremely high F-statistics (≥ 77,000), indicating no weak instrument problem. In the second-stage regressions (columns 2 and 4), DFI continues to have a significantly positive effect on sustainable development (SGR), with coefficients of 0.090 and 0.115, respectively, and high t-values, affirming the robustness of the main findings. Control variables show consistent patterns: firm age negatively affects SGR, while firm size, ownership concentration (Fir), and dual leadership have positive effects (Siddiqui et al., 2024). The proportion of independent directors (Inde) again shows a negative impact, and audit opinion (Aud) remains positively associated with SGR. The IV results strengthen the causal interpretation that digital finance significantly promotes corporate sustainability, even when accounting for potential reverse causality or omitted variable bias.

Table 6 Endogeneity Test of Explanatory Variable DFI Lagged One to Two Periods as Instrumental Variables

	lag one phase			Phase II lag	
variant		Phase I	Phase II	Phase I	Phase II
		(1) DFI	(2) SGR	(3) DFI	(4) SGR
DFI	DFI		0.090***		0.115***
			(16.48)		(17.48)
	DFI lagged by one period	0.665***		1.000***	
instrumental		(765.11)		(209.90)	
variable	DFI Lag II			0.159***	
				(-49.63)	
	Age	0.001***	-0.002***	0.000***	-0.001***
		(10.27)	(-5.81)	(2.91)	(-3.13)
	Size	-0.000	0.034***	0.000	0.025***
		(-0.75)	(19.89)	(1.34)	(14.91)
control variable	Fir	0.000	0.002***	0.000	0.002***
		(1.53)	(20.74)	(0.29)	(18.60)
	Dual	0.010***	0.013***	0.003***	0.007**
		(9.44)	(3.48)	(3.81)	(1.97)
	Inde	0.018**	-0.132***	0.011*	-0.136***

			(2.16)	(-4.20)	(1.68)	(-4.27)
		Aud	0.010**	0.421***	-0.003	0.273***
			(2.48)	(9.01)	(-0.91)	(5.50)
constant (math.)	term	_cons	1.971***	-1.334***	0.963***	-1.127***
			(206.35)	(-18.20)	(77.29)	(-14.18)
sample size		*N*	26453	26453	21189	21189
R2		r2	0.962	0.085	0.967	0.069
		r2_a	0.962	0.085	0.967	0.068
F-test		F	9.5e+04	144.362	7.7e+04	119.332

Table 8 presents the results of the mediation analysis examining whether total factor productivity (TFP) mediates the relationship between digital finance (DFI) and corporate sustainable development (SGR). In Model (1), DFI has a significant positive effect on SGR (coefficient = 0.063, t = 16.70). Model (2) confirms that DFI also significantly increases TFP (coefficient = 0.039, t = 5.07), indicating a potential transmission channel. In Model (3), when both DFI and TFP are included as predictors of SGR, both remain significant, with TFP positively associated with SGR (coefficient = 0.031, t = 7.52), and the DFI coefficient remains stable, suggesting a partial mediation effect. Control variables behave consistently across models: firm age negatively impacts SGR but positively affects TFP, while firm size and ownership concentration positively influence both outcomes. The results support the hypothesis that digital finance enhances corporate sustainability partly through improving firm productivity, validating TFP as an important mediating mechanism in this relationship.

Table 7 Regression analysis of the transmission mechanism of total factor productivity

	(1)	(2)	(3)
	SRG	TFP	SRG
DFI	0.063***	0.039***	0.064***
	(16.70)	(5.07)	(14.69)
TFP			0.031***
			(7.52)
Age	-0.004***	0.004***	-0.004***
	(-9.81)	(6.51)	(-9.17)
Size	0.044***	0.609***	0.036***
	(24.74)	(198.85)	(9.81)
Fir	0.003***	0.001***	0.003***
	(23.55)	(5.08)	(19.72)
Dual	0.021***	0.002	0.024***
	(5.08)	(0.25)	(5.33)
Inde	-0.178***	-0.130*	-0.194***
	(-5.13)	(-1.85)	(-5.13)
Aud	0.695***	0.007	0.669***
	(16.36)	(0.19)	(15.45)

_cons	-1.664***	-5.510***	-1.717***
	(-25.91)	(-64.95)	(-22.03)
N	33103	28645	28645
r2	0.128	0.630	0.137
r2_a	0.127	0.630	0.137
F	204.303	6454.168	197.665

Table 9 examines the mediating role of financial risk (FR) in the relationship between digital finance (DFI) and corporate sustainable development (SGR). In Model (1), DFI has a significant positive effect on SGR (coefficient = 0.063, t = 16.70). Model (2) shows that DFI significantly increases financial risk (coefficient = 0.120, t = 16.43), indicating a potential indirect pathway. In Model (3), both DFI and FR are included as predictors of SGR; FR shows a strong positive effect on SGR (coefficient = 0.254, t = 50.71), while the coefficient for DFI drops to 0.028 but remains significant, suggesting partial mediation. These results imply that while digital finance promotes sustainability directly, it also indirectly contributes by increasing financial exposure, which in turn stimulates firms to respond strategically, potentially enhancing long-term sustainability performance. Control variables remain consistent: age negatively affects SGR and FR, size has a mixed effect (negative on FR but positive on SGR), and audit opinion (Aud) strongly supports both financial transparency and sustainable outcomes. This table confirms that financial risk is a significant mediating mechanism through which digital finance influences enterprise sustainability.

Table 9 Regression analysis of the transmission mechanism of financial risk

	(1)	(2)	(3)
	SGR	FR	SGR
DFI	0.063***	0.120***	0.028***
	(16.70)	(16.43)	(8.47)
FR			0.254***
			(50.71)
Age	-0.004***	-0.007***	-0.002***
	(-9.81)	(-11.00)	(-5.10)
Size	0.044***	-0.091***	0.074***
	(24.74)	(-29.64)	(39.55)
Fir	0.003***	0.006***	0.001***
	(23.55)	(23.03)	(10.70)
Dual	0.021***	0.050***	0.010***
	(5.08)	(6.31)	(2.80)
Inde	-0.178***	-0.217***	-0.134***
	(-5.13)	(-3.20)	(-4.41)
Aud	0.695***	0.652***	0.519***
	(16.36)	(16.21)	(13.59)
_cons	-1.664***	2.157***	-2.341***

	(-25.91)	(24.82)	(-37.09)
N	33103	32093	32093
r2	0.128	0.071	0.335
r2_a	0.127	0.071	0.335
F	204.303	332.876	425.972

Table 10 presents the disaggregated regression results to examine the individual effects of the three dimensions of digital finance—breadth of coverage (DFW), depth of use (DFP), and level of digitization (DFE)—on corporate sustainable development (SGR). Model (1) confirms that the overall digital finance index (DFI) has a significant positive effect on SGR (coefficient = 0.063, t = 16.70). When broken down, all three components also exhibit significant positive relationships: DFW (0.058, t = 16.30), DFP (0.074, t = 18.09), and DFE (0.040, t = 13.58). Among them, depth of use (DFP) has the strongest effect, suggesting that the intensity with which firms engage with digital financial services plays a more critical role in driving sustainable outcomes than mere access or digital infrastructure (Rahman & Sadik, 2025). Control variables behave consistently across models: firm age negatively affects SGR, while firm size, ownership concentration (Fir), dual leadership (Dual), and audit opinion (Aud) all show positive and significant associations. The adjusted R^2 values remain stable (around 0.124–0.129), indicating comparable model fit. Overall, these results highlight that not only the presence but also the effective and deep usage of digital financial tools significantly enhances enterprise sustainability.

Table 10 Heterogeneity regression results for the Digital Finance Index

	digital finance	breadth of coverage	Depth of use	Level of digitisation
	(1) SGR	(2) SGR	(3) SGR	(4) SGR
DFI	0.063***			
	(16.70)			
DFW		0.058***		
		(16.30)		
DFP			0.074***	
			(18.09)	
DFE				0.040***
				(13.58)
Age	-0.004***	-0.004***	-0.004***	-0.003***
	(-9.81)	(-9.76)	(-10.09)	(-8.46)
Size	0.044***	0.043***	0.044***	0.044***
	(24.74)	(24.72)	(24.82)	(24.89)
Fir	0.003***	0.003***	0.003***	0.003***
	(23.55)	(23.48)	(23.61)	(23.37)
Dual	0.021***	0.021***	0.019***	0.025***
	(5.08)	(5.05)	(4.70)	(6.20)
Inde	-0.178***	-0.178***	-0.180***	-0.169***
	(-5.13)	(-5.12)	(-5.18)	(-4.87)

Aud	0.695***	0.695***	0.693***	0.700***
	(16.36)	(16.35)	(16.34)	(16.46)
_cons	-1.664***	-1.628***	-1.723***	-1.573***
	(-25.91)	(-25.63)	(-26.38)	(-25.17)
N	33103	33103	33103	33103
r2	0.128	0.128	0.129	0.124
r2_a	0.127	0.127	0.129	0.124
F	204.303	203.266	206.341	200.290

Table 11 presents the heterogeneity analysis of the impact of digital finance (DFI) on corporate sustainable development (SGR) by ownership type—state-owned enterprises (SOEs) and privately run firms. The results reveal a significantly stronger effect of DFI on privately run enterprises (coefficient = 0.076, t = 13.68) compared to SOEs (coefficient = 0.015, t = 2.42), suggesting that digital finance plays a more vital role in enhancing sustainability for private firms, which typically face greater financing constraints (Li et al., 2023). In both ownership types, firm size and ownership concentration (Fir) are positively associated with SGR, while firm age has a negative effect. The proportion of independent directors (Inde) shows a significantly negative impact in both models, especially among SOEs (–0.303), possibly reflecting governance inefficiencies or formalistic board roles. Audit opinion (Aud) positively influences SGR in both groups, with a slightly stronger effect in SOEs. Overall, the model explains more variance in the private firm sample (adjusted $R^2 = 0.160$) than in SOEs (adjusted $R^2 = 0.116$), reinforcing the conclusion that digital finance has a more substantial and transformative impact on sustainability performance in the private sector.

Table 11 Regression results of firm ownership heterogeneity analysis

	state enterprise	privately run
	(1) SGR	(2) SGR
DFI	0.015**	0.076***
	(2.42)	(13.68)
Age	-0.001**	-0.004***
	(-2.26)	(-7.49)
Size	0.043***	0.068***
	(15.99)	(20.56)
Fir	0.003***	0.004***
	(13.11)	(21.47)
Dual	0.005	0.005
	(0.46)	(1.11)
Inde	-0.303***	-0.121***
	(-4.96)	(-2.69)
Aud	0.818***	0.627***
	(9.62)	(11.56)
_cons	-1.552***	-2.216***
	(-14.70)	(-21.08)

N	11682	17836
r2	0.117	0.161
r2_a	0.116	0.160
F	83.238	126.464

Table 12 examines the heterogeneity in the effect of digital finance (DFI) on sustainable development (SGR) by firm size, comparing mega enterprises and medium-sized enterprises. The results reveal that while DFI significantly enhances sustainability in both groups, its impact is substantially stronger in medium-sized firms (coefficient = 0.170, t = 5.69) than in mega firms (coefficient = 0.061, t = 16.30). This suggests that digital finance may be particularly effective in alleviating growth constraints for smaller firms that typically face more limited access to traditional financial services (Jin & Liu, 2025). Other control variables show consistent patterns: firm age negatively affects SGR across both groups, with a larger effect size in medium firms. Firm size, ownership concentration (Fir), and audit quality (Aud) all positively influence SGR, with notably stronger coefficients in medium-sized enterprises. Dual leadership (Dual) and board independence (Inde) are significant only in mega firms, indicating differing governance dynamics by firm scale. The explanatory power of the model is also considerably higher for medium firms (adjusted $R^2 = 0.295$) than for mega firms (adjusted $R^2 = 0.108$), reinforcing that the sustainability benefits of digital finance are more pronounced among medium-sized enterprises.

Table 12 Regression results of firm size heterogeneity analysis

	mega	medium-sized
	(1) SGR	(2) SGR
DFI	0.061***	0.170***
	(16.30)	(5.69)
Age	-0.003***	-0.021***
	(-7.42)	(-7.40)
Size	0.036***	0.236***
	(21.89)	(9.83)
Fir	0.003***	0.007***
	(22.42)	(7.93)
Dual	0.021***	0.008
	(5.21)	(0.23)
Inde	-0.163***	-0.075
	(-4.77)	(-0.30)
Aud	0.635***	0.882***
	(14.37)	(7.47)
_cons	-1.426***	-6.415***
	(-22.17)	(-11.64)
N	31763	1340
r2	0.108	0.298
r2_a	0.108	0.295

F	175.383	33.533

Table 13 presents a heterogeneity analysis of the impact of digital finance (DFI) on sustainable development (SGR) across different sectors—industrial firms and service-sector firms. The results indicate that DFI significantly and positively influences SGR in both sectors, with similar coefficients (0.064 for industry and 0.060 for services), suggesting a broadly consistent effect of digital finance across economic activities (Rahman & Sadik, 2025). Firm age negatively affects sustainability in both sectors, while firm size, ownership concentration (Fir), and audit opinion (Aud) positively contribute to SGR. Dual leadership (Dual) shows a significant positive effect only in industrial firms, while it is insignificant in the service sector, potentially reflecting differing managerial dynamics. The proportion of independent directors (Inde) is negatively associated with SGR in both sectors, though the effect is slightly stronger in industrial firms. The models show good explanatory power, with adjusted R^2 values of 0.118 and 0.141, respectively, indicating that digital finance effectively promotes corporate sustainability regardless of sector, but may have slightly more explanatory strength within service-based firms.

Table 13 Regression results of firms' industry heterogeneity analysis

	industries	services sector
	(1) SGR	(2) SGR
DFI	0.064***	0.060***
	(12.68)	(10.36)
Age	-0.003***	-0.005***
	(-5.96)	(-7.74)
Size	0.036***	0.052***
	(17.57)	(17.55)
Fir	0.002***	0.003***
	(17.16)	(16.28)
Dual	0.026***	0.010
	(5.30)	(1.39)
Inde	-0.171***	-0.152***
	(-4.04)	(-2.64)
Aud	0.702***	0.685***
	(11.25)	(11.78)
_cons	-1.507***	-1.846***
	(-17.38)	(-19.15)
N	18424	14538
r2	0.119	0.141
r2_a	0.118	0.141
F	115.688	96.382

Table 14 analyzes regional heterogeneity in the effect of digital finance (DFI) on corporate sustainable development (SGR) across China's eastern, central, and western regions. The results show that DFI positively and significantly promotes SGR in all three regions, with the strongest effect observed in the eastern region

(coefficient = 0.062, t = 14.03), followed by the western (0.047, t = 4.08) and central regions (0.039, t = 4.06). This gradient likely reflects differences in digital infrastructure, economic development, and policy support. Firm age consistently shows a negative effect across regions, while firm size, ownership concentration (Fir), and audit opinion (Aud) positively influence SGR in all three. Interestingly, the proportion of independent directors (Inde) negatively affects SGR in the eastern and central regions but has a significantly positive effect in the western region, suggesting a region-specific governance impact. The explanatory power of the models increases from east to west, with adjusted R^2 rising from 0.112 to 0.179, implying that DFI may play an even more crucial role in enhancing sustainability outcomes in less developed western areas. Overall, the table highlights clear regional disparities in how digital finance influences corporate sustainability.

Table14 Regression results of the analysis of regional heterogeneity of enterprises

	eastern part	central section	western part
	(1) SGR	(2) SGR	(3) SGR
DFI	0.062***	0.039***	0.047***
	(14.03)	(4.06)	(4.08)
Age	-0.002***	-0.009***	-0.008***
	(-4.70)	(-6.43)	(-5.90)
Size	0.033***	0.077***	0.084***
	(19.85)	(10.76)	(11.87)
Fir	0.003***	0.003***	0.003***
	(20.96)	(9.03)	(7.38)
Dual	0.014***	0.043***	0.007
	(3.41)	(3.20)	(0.41)
Inde	-0.208***	-0.455***	0.271**
	(-5.81)	(-3.73)	(2.30)
Aud	0.603***	0.780***	0.821***
	(11.67)	(7.47)	(7.95)
_cons	-1.334***	-2.209***	-2.729***
	(-18.29)	(-11.67)	(-13.66)
N	23005	4644	4184
r2	0.113	0.154	0.181
r2_a	0.112	0.153	0.179
F	144.317	35.707	36.877

5. Discussion

This study investigates the impact of digital finance on corporate sustainable development in China, emphasizing the mediating mechanisms of total factor productivity (TFP) and financial risk (FR), and analyzing heterogeneity across firm ownership, size, sector, and region.The study contributes to the growing literature on the intersection of digital finance and sustainability by validating a causal and positive relationship between digital financial development and firms' sustainable growth. Unlike previous studies that primarily focused on macroeconomic or consumer-level outcomes (Magnani, 2020; Tanner et al., 2020), this paper

deepens the understanding of how digital finance affects firm-level sustainability performance. By incorporating TFP and FR as mediating variables, the study extends the resource-based and risk management perspectives to reveal how digital finance enhances sustainability through improved productivity and by reshaping firms' risk exposure. Furthermore, the decomposition of digital finance into breadth of coverage, depth of use, and digitization level provides a more granular view of its functional dimensions, enriching the theoretical dialogue on digital financial infrastructure.

In terms of practical implications, the findings underscore the significant role digital finance plays in improving corporate sustainability, especially among private, medium-sized, and western-region firms. This suggests that targeted digital financial policies can serve as effective tools to reduce financing constraints and promote inclusive growth. The stronger impact of digital finance in less developed regions and among smaller enterprises highlights its potential to level the playing field and foster more balanced regional development. Policymakers and financial institutions should prioritize digital infrastructure and services that promote deeper usage and functionality rather than just access, as the "depth of use" emerged as the most influential component. In addition, the positive mediating role of financial risk indicates that firms respond to heightened financial exposure with more sustainable strategies, suggesting that properly designed risk environments can incentivize responsible corporate behavior.

The results of this study consistently demonstrate that digital finance is a catalyst for sustainable transformation, with robust effects across multiple firm and regional categories. The baseline regressions confirm a significant positive effect of digital finance on sustainability. The mediation models further reveal that TFP enhances and FR moderates this relationship. Heterogeneity tests indicate that the influence of digital finance is more pronounced in private enterprises, medium-sized firms, service industries, and firms located in central and western regions. Notably, while independent directors are expected to exert positive governance effects, the findings suggest a more complex role, with negative effects in most subgroups, possibly due to formalistic governance structures or inefficiencies in board participation.

Nevertheless, this study has several limitations. First, while the use of instrumental variable regression addresses endogeneity to a degree, the reliance on secondary data limits the depth of behavioral and strategic interpretations. Second, the study focuses on Chinese listed firms, which may not fully capture the dynamics in SMEs or unlisted entities. Third, digital finance is measured at the regional level, potentially obscuring firm-specific variations in digital engagement. Future research could employ micro-level digital finance indicators and explore cross-country comparative frameworks. In addition, incorporating qualitative case studies could enrich understanding of the organizational mechanisms behind the observed statistical relationships.

6. Conclusion

This study set out to explore the impact of digital finance on corporate sustainable development in China using a large panel dataset of A-share listed firms from 2011 to 2022. Grounded in the theoretical foundations of resource optimization and risk management, the research constructed a robust empirical model to assess both direct and indirect effects of digital finance. It further dissected the roles of three dimensions—coverage breadth, usage depth, and digitalization level—and examined mediating pathways via total factor productivity (TFP) and financial risk (FR). The study also introduced heterogeneity tests across ownership types, firm sizes, industrial sectors, and geographic regions.

The empirical findings confirm that digital finance significantly promotes corporate sustainability.

Among the sub-dimensions, depth of use exerts the strongest positive influence, implying that the quality of financial engagement matters more than mere access. Moreover, the mediating effect of TFP suggests that digital finance enhances sustainability by improving firms' productivity and innovation efficiency. In contrast, FR plays a complex dual role—while higher financial risk stimulates sustainable response, it also reflects underlying exposure. Heterogeneity analysis reveals that the effect of digital finance is more prominent in privately run, medium-sized, service-oriented, and western-based enterprises, indicating its role in bridging financial and developmental gaps.

Theoretically, this research enriches the literature by offering a comprehensive micro-level assessment of how digital finance advances sustainable outcomes. Practically, it suggests that policy efforts should prioritize not only digital inclusion but also deep and functional use of digital tools, especially in regions and sectors with lower baseline capacities. By clarifying how and for whom digital finance works best, the study provides targeted insights for financial regulators, corporate strategists, and development planners.

Future studies may consider incorporating more granular indicators of firm-level digital finance adoption and exploring international comparative datasets. A mixed-method approach could further reveal managerial perspectives on how digital tools reshape sustainability practices. In sum, digital finance holds substantial potential to be a transformative force for sustainable corporate growth—provided it is strategically integrated and inclusively deployed.

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