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Research on the Impact of Digital-Physical Technology Integration on Firm Resilience

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Abstract

Digital-physical technology integration is an essential part of the deep convergence of the digital and physical economies, contributing significantly to improving the survival and growth opportunities of firms in uncertain environments. Using a sample of Shanghai and Shenzhen A-share listed companies from 2015 to 2024, this paper empirically investigates the impact of digital-physical technology integration on firm resilience and the underlying mechanisms. The results indicate that digital-physical technology integration significantly enhances firm resilience. The baseline regression findings remain robust after introducing individual and time fixed effects. The conclusion holds following a series of robustness tests, including instrumental variable estimation, propensity score matching, heteroskedasticity-robust standard errors, exclusion of municipalities, alternative winsorization thresholds, and sample period adjustments. Mechanism tests reveal that digital-physical technology integration improves firm resilience through two primary channels: augmenting innovation capacity and alleviating financing constraints. Heterogeneity analysis further demonstrates that this positive effect is more pronounced among non-state-owned enterprises, non-polluting firms, high-tech industries, firms with lower market power, enterprises located in eastern regions, and those receiving higher government subsidies. This study extends the existing literature on the enabling effects of digital-physical technology integration from the perspective of firm resilience, providing empirical support for firms seeking to build resilience in the digital age and offering theoretical foundations and practical insights for policymakers aiming to promote deeper digital-physical integration and more efficient resource allocation.

Keywords

digital-physical technology integration, firm resilience, innovation capacity, financing constraints, instrumental variable approach

1. Introduction

The global economy is experiencing multiple overlapping crises, with geopolitical conflicts and supply chain disruptions rendering the business environment highly uncertain. Maintaining stable operations and achieving counter-cyclical growth have thus become focal concerns. Meanwhile, the integration of the digital and physical economies is regarded as a crucial pathway to high-quality development and has been elevated to a national strategic priority following the launch of China's “Internet Plus” action plan in 2015. At the firm level, whether and how the integration of digital and physical industrial technologies can enhance resilience remains an urgent and significant question requiring empirical investigation.

Although digital-physical integration has been recognized as strategically important, its implementation at the firm level encounters major challenges. Many enterprises view digital transformation merely as hardware upgrades, overlooking the synergy between technology and organizational adaptation. Such a "form over substance" approach may, in fact, undermine long-term resilience [1]. Moreover, firms are often constrained by limited innovation capacity and restricted access to financing, hindering their ability to achieve deep integration. As external shocks become more frequent, enterprises lacking sufficient resilience are particularly vulnerable to failure. Therefore, exploring the pathways and contextual conditions through which digital-physical integration enhances resilience holds both theoretical significance and pressing practical value.

Extant literature has examined the antecedents of firm resilience. From a supply chain coordination perspective, the integration of digital and physical industrial technologies can enhance supply chain stability [2]. Studies grounded in dynamic capabilities theory suggest that digital transformation strengthens resilience by improving agile responsiveness [3]. Positive effects of digital-green synergistic transformation and digital-physical economic integration on resilience have also received empirical support [4]. However, these studies primarily focus on macro-level integration or generalized digitalization levels, rarely conceptualizing and measuring firm-level digital-physical technology integration as a distinct construct. Mechanism analyses often remain confined to a single pathway, overlooking the dual transmission roles of innovation capacity and financing constraints. Furthermore, discussions of heterogeneity tend to be fragmented.

To address these gaps, this study utilizes a sample of Chinese A-share listed firms from 2015 to 2024 to empirically examine the effect and mechanisms of digital-physical technology integration on firm resilience. The contributions of this paper are threefold: First, it focuses on firm-level integration behavior, constructing a novel measure based on patent citation networks. Second, it simultaneously investigates two parallel transmission pathways—innovation capacity and financing constraints. Third, it conducts comprehensive heterogeneity analyses across firm characteristics, industry attributes, and regional settings.

2. Theoretical Analysis and Research Hypotheses

2.1 Digital-Physical Technology Integration and Firm Resilience

In the context of the profound intersection of the digital and physical economies, firms have to face an environment characterized by a high level of uncertainty. The ability to endure external shocks, rebound rapidly, and capitalize on adverse circumstances has become central to firm survival. Digital-physical technology integration—understood as the cross-penetration and synergistic innovation of digital technologies and tangible industrial technologies—constitutes a key dimension of this broader convergence, progressively reshaping firm capabilities and strengthening organizational resilience. Drawing upon resource dependence theory, the resource-based view, and dynamic capabilities theory, this section explains its promoting effect through three lenses: supply chain coordination, optimization of resource allocation, and building dynamic capabilities.

To begin with, digital-physical technology integration dismantles informational silos, thereby improving supply chain coordination and responsiveness (Li & Jin, 2025). According to resource dependence theory, close collaboration in the supply chain mitigates external uncertainties. When suppliers embed digital technologies and interface with client systems, real-time sharing of inventory and demand data enhances buffering and recovery capacity. Systemic risks are also reduced through standardized technological interfaces [5]. Second, this integration facilitates the movement of data as a factor of production, improving the efficiency of resource allocation and operational agility [6]. By reducing information and coordination costs, technology convergence enables firms to promptly correct resource misallocations. Data-driven decision-making allows for rapid responses to external changes, serving as both a buffer against disruptions and a foundation for post-crisis recovery [7]. Finally, as a process of cross-domain knowledge recombination, digital-physical technology integration fortifies dynamic capabilities: it enhances risk perception (via real-time monitoring of market and supply chain risks), resource acquisition (by transcending organizational boundaries to access technological and market intelligence), and resource transformation (through the internalization of external knowledge to reconfigure processes and business models) [8]. This chain—from perception to reconfiguration—enables firms not only to survive crises but also to achieve capability leaps, driving a qualitative evolution of resilience from passive response to proactive adaptation.

Based on this, this paper puts forward the following hypotheses:

Hypothesis 1: Digital-physical technology integration significantly enhances firm resilience.

2.2 Digital-Physical Technology Integration, Innovation Capacity, and Firm Resilience

Digital-physical technology integration enhances firm resilience by augmenting innovation capacity. The convergence of digital and industrial technologies is fundamentally a cross-domain knowledge recombination process, which lowers innovation barriers, broadens boundaries, and improves efficiency. Enhanced innovation capability, in turn, provides firms with the internal strength required to sustain competitive advantage and navigate external shocks in uncertain times.

Digital-physical technology integration strengthens innovation capacity through three dimensions: (1) technological tools—digital embedding enables real-time data capture and bottleneck identification, driving problem-focused innovation [9]; (2) knowledge sources—integration breaks closed knowledge silos, allowing firms to acquire cross-domain information digitally and recombine it with internal know-how, thereby increasing both the quantity and quality of innovation [10]; (3) organizational cognition—integration fosters managerial optimism toward innovation and reduces perceived technological uncertainty, reinforcing the commitment to sustained innovation [11]. Strengthened innovation capacity, in turn, bolsters firm resilience: firms with richer technological portfolios adjust product lines more rapidly amid shocks, mitigating single-business risk [12]; they develop alternative processes more swiftly during supply or technology disruptions; and they pursue counter-cyclical growth through continuous upgrading. Over time, such firms achieve higher productivity and greater financial stability, securing more slack and strategic flexibility to withstand and recover from crises [10].

Based on this, this paper puts forward the following hypotheses:

Hypothesis 2: Digital-physical technology integration enhances firm resilience by improving innovation capacity.

2.3 Digital-Physical Technology Integration, Financing Constraints, and Firm Resilience

Digital-physical technology integration strengthens firm resilience by alleviating financing constraints. Financing constraints refer to barriers in accessing external funds arising from information asymmetry, high transaction costs, or insufficient collateral. Firms facing severe financing constraints struggle to maintain operations during external shocks, whereas the alleviation of these constraints provides crucial financial protection for navigating crises.

Digital-physical technology integration mitigates financing constraints through three primary channels: enhanced information transparency, improved asset value, and increased external trust. First, the digital representation of production and operational data allows financial institutions to access real-time information, reducing information asymmetry and credit rationing [13]. Second, integration elevates the digital traceability and functionality of fixed assets, thereby enhancing their liquidity and collateral value. Third, it signals technological advancement and promising growth prospects to investors, thereby improving credit ratings and access to financing (Ma & Gong, 2025). Alleviating financing constraints, in turn, bolsters resilience by providing financial buffers and strategic flexibility. When faced with plummeting demand or supply chain disruptions, firms with relaxed financing constraints can swiftly secure external funding to cover operational expenses and avert cash flow crises (Chen et al., 2023). Ample liquidity also supports counter-cyclical investments, such as increased R&D or strategic acquisitions, enabling firms to seize post-crisis opportunities. Moreover, reduced financing constraints lessen the need for precautionary savings, freeing up capital for long-term capability building. Improvements in financing conditions significantly reduce financial volatility and enhance performance growth, directly reflecting strengthened firm resilience [10].

Based on this, this paper puts forward the following hypotheses:

Hypothesis 3: Digital-physical technology integration enhances firm resilience by alleviating financing constraints.

3. Research Design

3.1 Model Specification

To verify the impact of digital-physical technology integration on firm resilience, we construct the following econometric model:

$$\mathrm{Resilience}_{i,t} = \alpha + \beta \mathrm{CEDRT}_{i,t} + \gamma \mathrm{controls}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Among them, the explained variable is Resilience, and the core independent variable is CEDRT the integration of digital-physical technologies, controls which is the control variable, the individual μ_i fixed effect, and λ_t the time fixed effect, ε is a random perturbation term.

Further, this paper uses a two-step method to test the mechanism of digital-physical technology integration on firm resilience, and the model is:

$$\mathrm{M}_{i,t} = b_0 + b_1 \mathrm{CEDRT}_{i,t} + \beta \mathrm{controls}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

Where the mechanism variable M represents either financing constraints (SA index) or innovation capacity (Patent filings).

3.2 Variable Definition

3.2.1 Dependent Variable

Firm Resilience (Resilience). Following the approach of Tian et al. [14], we measure firm resilience as the change in total factor productivity (TFP) relative to the previous period. The calculation is as follows:

$$\mathrm{Resilience}_{it} = \mathrm{TFP}_{it} - \mathrm{TFP}_{it-1}$$

3.2.2 Core Independent Variable

Digital-Physical Technology Integration (CEDRT). To objectively gauge the degree of firm-level digital-physical technology integration, we adopt the methodology of Guo et al. [15], employing a patent citation network analysis. The measure is calculated as the natural logarithm of one plus the frequency of technology integration citations.

3.2.3 Mechanism Variables

This study employs financing constraints and innovation capacity as mechanism variables. Financing Constraints (SA) are measured using the SA index (Zheng et al., 2026). Innovation Capacity (Patent) is measured as the natural logarithm of one plus the total number of invention patent, utility model patent, and design patent applications filed by the firm in a given year .

3.2.4 Control Variables

To mitigate omitted variable bias, we include a set of control variables based on prior research [16]: Firm Size (Size), Prior-Year Loss Indicator (Loss), Fixed Asset Ratio (Fixed), Leverage Ratio (Lev), Independent Director Ratio (Indep), Profitability (ROA), Board Size (Board), and CEO Duality (Dual).

Detailed definitions and descriptions for all variables are presented in Table 1.

Table 1: Variable Definitions and Descriptions

Variable type	Variable name	Symbols	Description
Dependent Variable	Firm Resilience	Resilience	Constructed based on Total Factor Productivity (TFP) change.
Independent Variable	Digital-Physical Tech Integration	CEDRT	Constructed using patent citation network data.
Mechanism Variables	Financing Constraints	SA	Measured using the SA Index.
	Innovation Capacity	Patent	Natural log of one plus total patent applications (invention, utility, design).
	Firm Size	Size	Natural logarithm of total assets.

Variable type	Variable name	Symbols	Description
Control Variables	Prior-Year Loss	Loss	Dummy variable equal to 1 if net income in the previous year was negative, else 0.
	Fixed Asset Ratio	Fixed	Net fixed assets divided by total assets.
	Leverage Ratio	Lev	Total liabilities divided by total assets.
	Independent Director Ratio	Indep	Number of independent directors divided by total board members.
	Profitability	ROA	Net income divided by average total assets.
	Board Size	Board	Number of directors on the board.
	CEO Duality	Dual	Dummy variable equal to 1 if the CEO and board chair are the same person, else 0.

3.3 Sample Selection and Data Sources

Our initial sample consists of A-share listed firms on the Shanghai and Shenzhen Stock Exchanges from 2015 to 2024. We filter the sample according to the following criteria: (1) exclude companies containing "ST" or "*ST" in the stock abbreviation; (2) Exclude listed companies in the financial industry; (3) deletion of observations with missing values for primary regression variables; (4) winsorization of all continuous variables at the 1st and 99th percentiles. This process yields a final sample of 26,242 firm-year observations. Firm-level patent data are sourced from the China National Intellectual Property Administration (CNIPA) patent database and the China Patent Retrieval System, utilized for constructing the digital-physical technology integration and firm resilience metrics. Data for all remaining variables are primarily obtained from the China Stock Market & Accounting Research (CSMAR) database.

4. Empirical Analysis

4.1 Descriptive Statistics

Descriptive statistics for the main variables are reported in Table 2. The median value of Firm Resilience (Resilience) is 0.0037, with a standard deviation of 0.1420. The median value of Digital-Physical Technology Integration (CEDRT) is 0.0000, with a standard deviation of 0.2400. These figures indicate substantial variation in both firm resilience and digital-physical technology integration across the sample.

Table 2: Descriptive Statistics

Variable	N	Min	Max	Mean	p50	SD
CEDRT	26242	0.0000	1.3860	0.0661	0.0000	0.2400
Resilience	26242	-0.5090	0.5400	-0.0022	0.0037	0.1420
Loss	26242	0.0000	1.0000	0.1140	0.0000	0.3180
Size	26242	20.1900	26.4200	22.3900	22.1900	1.2800
Lev	26242	0.0636	0.8860	0.4150	0.4070	0.1940
ROA	26242	-0.2340	0.1970	0.0330	0.0348	0.0637
Fixed	26242	0.0038	0.6380	0.2040	0.1780	0.1420
Indep	26242	0.3330	0.5710	0.3790	0.3640	0.0535
Board	26242	1.6090	2.5650	2.0970	2.1970	0.1940
Dual	26242	0.0000	1.0000	0.3280	0.0000	0.4690

4.2 Benchmark Regression Test

Table 3 presents the baseline regression results. Column (1), which excludes control variables, shows that the coefficient for Digital-Physical Technology Integration (CEDRT) on Firm Resilience (Resilience) is positive (0.0213) and statistically significant at the 1% level. Column (2), which incorporates the full set of control variables, yields a similarly positive and significant coefficient (0.0207) at the 1% level. These findings indicate that digital-physical technology integration significantly enhances firm resilience, thereby supporting Hypothesis 1.

Table 3: Baseline Regression

	(1)	(2)
VARIABLES	Resilience	Resilience
CEDRT	0.0213***	0.0207***
	(5.0072)	(5.0241)
Constant	-0.0133***	1.3710***
	(-3.4042)	(17.0508)
Controls	NO	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	26,242	26,242
R-squared	0.2270	0.2730
Adj. R2	0.1230	0.1230

*Note: *** p<0.01, ** p<0.05, * p<0.10. t-statistics in parentheses.*

4.3 Mechanism Analysis

The results of the mechanism tests are displayed in Table 4. Column (1) shows a positive and statistically significant coefficient (0.1306, p<0.01) for CEDRT when regressed on innovation capacity (Patent), suggesting that digital-physical technology integration enhances firm resilience by fostering innovation capacity. Column (2) reports a negative and statistically significant coefficient (-0.0038, p<0.01) for CEDRT when regressed on financing constraints (SA), indicating that integration alleviates financing constraints, which in turn bolsters firm resilience. These results provide empirical support for Hypotheses 2 and 3.

Table 4: Mechanism Test

	(1)	(2)
VARIABLES	Patent	SA
CEDRT	0.1306***	-0.0038***
	(5.8592)	(-3.2373)
Constant	-9.6096***	-3.9821***
	(-21.8069)	(-172.8355)
Controls	NO	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	25,468	26,242
R-squared	0.8170	0.9840
Adj. R2	0.9810	0.9810

4.4 Endogeneity Tests

4.4.1 Instrumental Variable (IV) Approach

First, drawing on the research design of Chen and Guo [17], we employ the “Management Digital Transformation Strategic Leadership Score” (IV1) as an instrumental variable for digital-physical technology integration. This indicator, sourced from the CSMAR database, is a composite index constructed using the entropy method based on five dimensions: establishment of digital executive roles, and the foresight, continuity, breadth, and intensity of digital innovation strategy. Theoretically, management's cognitive awareness of digitalization directly influences the advancement of the firm's digital strategy, thereby driving the level of digital-physical technology integration [18], satisfying the relevance criterion. Moreover, managerial digital awareness, as a strategic cognition, is unlikely to exert a direct impact on firm resilience independent of operational behaviors, thus fulfilling the exogeneity condition.

The first-stage regression results are presented in Column (1) of Table 5. The estimated coefficient for IV1 is positive (0.0006) and significant at the 1% level (t=8.2125), confirming that managerial digital awareness significantly promotes digital-physical technology integration. The second-stage results, shown in Column (2), indicate that the coefficient for CEDRT remains positive (0.4784) and significant at the 1% level, affirming that even after controlling for potential endogeneity, digital-physical technology integration positively affects firm resilience.

Additionally, to further address endogeneity concerns stemming from omitted variables or measurement error, we conduct a supplementary test using a constructed instrumental variable. Specifically, we utilize the "median level of digital-physical technology integration among other firms in the same industry, province, and year" (IV2). Firms operating within the same province and industry are subject to similar market environments and policy influences, ensuring a strong correlation with the focal firm's integration level. However, the average integration level of peer firms is unlikely to directly determine the focal firm's resilience, thereby satisfying the exogeneity requirement.

Column (3) of Table 5 reports the first-stage estimation results for IV2. The coefficient is positive (0.8732) and highly significant at the 1% level (t=71.3728), demonstrating strong explanatory power. The second-stage results, shown in Column (4), confirm that the coefficient for CEDRT is positive (0.0175) and statistically significant at the 5% level, consistent with the findings from the primary IV analysis. This further corroborates the positive influence of digital-physical technology integration on firm resilience.

4.4.2 Propensity Score Matching Method (PSM)

Considering that systematic differences in observable characteristics might introduce estimation bias, we employ propensity score matching as a robustness check. First, we partition the sample into high-integration and low-integration groups based on the industry-year median of CEDRT. Next, we estimate propensity scores using a set of covariates including firm size, leverage, and profitability, and perform one-to-one nearest-neighbor matching. Regression results using the matched sample are presented in Columns (5) and (6) of Table 5. The coefficient for CEDRT is positive (0.0254, t=3.2429) and significant at the 1% level without control variables (Column 5), and remains positive (0.0235) and significant at the 1% level with the inclusion of all control variables (Column 6). These findings indicate that sample self-selection bias does not materially alter our core conclusions.

Table 5: Endogeneity Test Results

	(1)	(2)	(3)	(4)	(5)	(6)
	first	second	first	second	first	second
VARIABLES	CEDRT	Resilience	CEDRT	Resilience	Resilience	Resilience
IV1	0.0006***					
	(8.2125)					
CEDRT		0.4784***		0.0175**	0.0254***	0.0235***
		(5.2857)		(1.9608)	(3.2429)	(3.1024)
IV2			0.8732***			
			(71.3728)			
Constant	-0.0212	-0.0318	0.0361	-0.0459**	-0.0091	1.0405***
	(-0.5682)	(-1.1418)	(1.0582)	(-2.1101)	(-0.8675)	(3.8108)
Controls	NO	YES	NO	YES	NO	YES
Observations	26,232	26,232	26,242	26,242	3,494	3,494
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
R-squared	0.045	-0.510	0.198	0.064	0.690	0.713
Adj. R2	0.0439		0.197	0.0637	0.290	0.290

4.5 Robustness Checks

4.5.1 Heteroskedasticity-Robust Standard Errors

For this robustness check, we re-estimate the baseline model using heteroskedasticity-robust standard errors. As shown in column (1) of Table 6, the estimated coefficient of the CEDRT is 0.0207 and is still significant at the statistical level of 1% (t=6.2256). The core finding remains unchanged.

4.5.2 Exclusion of Municipalities

Following the approach of Zhang et al. (2026), we re-run the regression after excluding observations from the four directly administered municipalities. As shown in Column (2) of Table 6, the coefficient for CEDRT is 0.0202 and significant at the 1% level (t=4.6645), confirming the robustness of the results.

4.5.3 Alternative Winsorization Threshold

We re-examine the model after applying a 5% winsorization threshold to continuous variables. As reported in Column (3) of Table 6, the coefficient for CEDRT is 0.0164 and remains significant at the 1% level (t=4.3093). The conclusion remains robust.

4.5.4 Reduced Sample Period

Consistent with Zhang et al. [19], we exclude observations from the period 2020–2022 to rule out the impact of the COVID-19 pandemic on our results. Results presented in Column (4) of Table 6 show that the coefficient for CEDRT is 0.0240 and significant at the 1% level (t=4.4703), further reinforcing the robustness of our findings.

Table 6: Robustness Test

	(1)	(2)	(3)	(4)
	Robust SE	Excl. Municipalities	Winsor 5%	Excl. 2020-2022
VARIABLES	Resilience	Resilience	Resilience	Resilience
CEDRT	0.0207***	0.0202***	0.0164***	0.0219***
	(6.2256)	(4.6645)	(4.3093)	(3.7244)
Constant	1.3710***	1.4708***	0.9183***	1.4771***
	(13.8825)	(17.1018)	(15.0768)	(14.8921)
Controls	YES	YES	YES	YES
Observations	26,242	21,939	26,242	18,299
R-squared	0.2730	0.2730	0.2750	0.3420
Adj. R2	0.1230	0.1250	0.1260	0.1310

4.6 Heterogeneity Analysis

4.6.1 Enterprise Level

(1) Ownership Structure

Columns (1) and (2) of Table 7 report subsample regression results based on ownership structure. The coefficient for CEDRT is 0.0111 (significant at the 10% level) for state-owned enterprises (SOEs) and 0.0253 (significant at the 1% level) for non-SOEs. This indicates that the resilience-enhancing effect of digital-physical technology integration is more pronounced in non-state-owned enterprises.

(2) Pollution Attributes

Columns (3) and (4) of Table 7 present results for subsamples categorized by whether the firm operates in a polluting industry. For polluting firms, the CEDRT coefficient (0.0062) is not statistically significant. Conversely, for non-polluting firms, the coefficient is 0.0240 and significant at the 1% level. This suggests that the positive effect is evident in non-polluting firms but not yet observable among polluting firms.

Table 7: Heterogeneity Test: Enterprise Level

	(1)	(2)	(3)	(4)
	State-owned enterprises	Non-state-owned enterprises	polluting enterprises	Non-polluting enterprises
VARIABLES	Resilience	Resilience	Resilience	Resilience
CEDRT	0.0111*	0.0253***	0.0062	0.0240***
	(1.6795)	(4.8445)	(0.7533)	(5.0725)
Constant	1.7000***	1.2767***	1.2398***	1.4431***
	(11.4718)	(12.9194)	(8.6186)	(14.9903)
Controls	YES	YES	YES	YES
Observations	7,656	18,586	5,878	20,364
R-squared	0.2950	0.2820	0.3170	0.2770
Adj. R2	0.1190	0.1190	0.1210	0.1210

4.6.2 Industry Level

(1) Industry Attributes

Columns (1) and (2) of Table 8 display results for high-tech versus non-high-tech industries. The coefficient for CEDRT is 0.0188 ($p<0.01$) for high-tech firms and 0.0217 ($p<0.05$) for non-high-tech firms. While the promoting effect exists across both industry types, it appears more pronounced within high-tech sectors.

(2) Industry Lerner Index

Columns (3) and (4) of Table 8 show subsample results split by the median industry Lerner Index. In the high market power group, the CEDRT coefficient is 0.0132 ($p<0.05$). In the low market power group, the coefficient is 0.0255 ($p<0.01$). This reveals that digital-physical technology integration significantly enhances resilience across firms with varying market power, but the effect is notably stronger for firms with lower market power.

Table 8: Heterogeneity Testing: Industry Level

	(1)	(2)	(3)	(4)
	High-Tech	Non-High-Tech	High Mkt Power	Low Mkt Power
VARIABLES	Resilience	Resilience	Resilience	Resilience
CEDRT	0.0188***	0.0217**	0.0132**	0.0255***
	(3.9721)	(2.5605)	(2.3759)	(3.6921)
Constant	1.3754***	1.3972***	1.1567***	1.3286***
	(13.9444)	(9.5643)	(10.3326)	(10.6038)
Controls	YES	YES	YES	YES
Observations	17,615	8,627	13,991	12,251
R-squared	0.2990	0.2720	0.3890	0.4770
Adj. R2	0.1100	0.1100	0.2080	0.2080

4.6.3 Regional Level

(1) Geographic Distribution

Columns (1) and (2) of Table 9 report results based on whether a firm is located in the central/western regions or the eastern region of China. For firms in the central/western regions, the coefficient for CEDRT (0.0095) is not statistically significant. In contrast, for firms in the eastern region, the coefficient is 0.0251 and significant at the 1% level. This suggests that digital-physical technology integration significantly enhances resilience for firms in the eastern region, but its effect is not evident in the central and western regions.

(2) Government Subsidies

Columns (3) and (4) of Table 9 present subsample results partitioned by the median amount of government subsidies received. In the high-subsidy group, the CEDRT coefficient is 0.0252 ($p<0.01$). In the low-subsidy group, the coefficient is 0.0129 ($p<0.10$). This indicates that the beneficial impact of digital-physical technology integration on firm resilience is more substantial among firms receiving higher levels of government support.

Table 9: Heterogeneity Test: Regional Level

	(1)	(2)	(3)	(4)
	Central/West	Eastern Region	High Subsidy	Low Subsidy
VARIABLES	Resilience	Resilience	Resilience	Resilience
CEDRT	0.0095	0.0251***	0.0252***	0.0129*
	(1.2242)	(5.1642)	(4.8827)	(1.6843)
Constant	1.5489***	1.2861***	1.3098***	1.3041***
	(9.7414)	(13.6707)	(11.7622)	(9.1672)
Controls	YES	YES	YES	YES
Observations	7,084	19,158	14,450	11,792
R-squared	0.2710	0.2800	0.3460	0.4050
Adj. R2	0.1280	0.1280	0.1490	0.1490

5. Conclusions and Implications

5.1 Research Conclusions

As a crucial engine for promoting high-quality economic development, the enabling effects of digital-physical technology integration at the micro-firm level have garnered increasing attention. Based on data from Chinese A-share listed companies spanning 2015 to 2024, this study systematically investigates the impact of digital-physical technology integration on firm resilience and its underlying mechanisms. The principal conclusions are as follows:

First, digital-physical technology integration significantly enhances firm resilience, a finding that remains robust across a battery of sensitivity and endogeneity tests. Second, mechanism analysis reveals that digital-physical technology integration strengthens firm resilience through two distinct channels: by fostering innovation capacity and by mitigating financing constraints. Third, heterogeneity analysis demonstrates that this positive impact is more pronounced among non-state-owned enterprises, non-polluting firms, high-tech industries, firms with lower market power, enterprises located in the eastern region, and those receiving higher government subsidies.

5.2 Policy and Practical Implications

Based on the conclusions drawn above, this paper offers the following policy and practical implications:

To begin with, firms ought to proactively embed digital-physical technology integration into their core strategic agenda and strengthen their capacity to absorb and assimilate digital technologies. To compensate for resource limitations and enhance their resilience to risks and recovery capabilities, non-state-owned enterprises and firms with lower market power should capitalize on the benefits of integration in reducing costs, improving efficiency, optimizing workflows, and enhancing responsiveness.

Second, government entities should implement differentiated support policies to precisely empower groups where the integration effect remains relatively weak. For firms located in central and western regions, polluting industries, and non-high-tech sectors, policies should focus on increasing digital infrastructure investment, providing targeted technical transformation subsidies, and establishing technology-sharing platforms to lower integration barriers. Concurrently, for regions and sectors where the integration effect is already substantial—such as eastern regions and high-tech industries—authorities should encourage them to serve as demonstration leaders and develop replicable models of digital-physical technology integration.

Third, financial and regulatory institutions should strive to optimize the financing environment for firms, thereby alleviating capital constraints encountered during the digital-physical technology integration process. Measures such as refining corporate credit evaluation systems, promoting intellectual property-backed financing, and establishing special credit lines for digital transformation can broaden firms' access to funding, reduce integration costs, and amplify the transmission efficiency from digital-physical technology integration to enhanced resilience.

Fourth, when advancing digital-physical technology integration, firms must emphasize the synergistic enhancement of internal governance structures and organizational capabilities. To avoid the pitfall of prioritizing technology adoption over capability internalization, it is advisable to establish cross-departmental digital promotion mechanisms and invest in cultivating digital talent. Such an approach ensures that technological dividends are effectively translated into sustained improvements in firm resilience.

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Conflicts of Interest

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