Research on the Impact of Digital Infrastructure Construction on China's Export Resilience

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Abstract. Against the backdrop of persistent turbulence in the global trade environment, enhancing export resilience is crucial to the high-quality development of China's foreign trade. As the underlying foundation of the digital economy, digital infrastructure plays a vital role in stabilizing exports and withstanding external shocks. This paper employs provincial panel data from China spanning 2010 to 2023, constructs a comprehensive index to measure the level of digital infrastructure development, and calculates an export resilience indicator. Using a two-way fixed-effects model for empirical analysis, the study finds that: the improvement of digital infrastructure significantly enhances regional export resilience, and this conclusion remains valid after robustness tests; mechanism analysis shows that enhanced supply chain flexibility and expanded openness are important transmission channels; heterogeneity analysis indicates that the empowering effect of digital infrastructure is more pronounced in central and western provinces and in regions with high e-commerce activity. Based on these findings, the paper proposes policy recommendations such as differentiated deployment of regional digital infrastructure and coordinated development of hardware construction and market applications, providing decision-making references for fostering foreign trade risk-resistance capacity.

Keywords: digital infrastructure, export resilience, supply chain flexibility, openness.

1. Introduction

Against the backdrop of intensifying global trade frictions, geopolitical conflicts and economic downturns, the stability of global supply chains has been severely disrupted. The WTO has downgraded growth forecasts for global goods trade, making the enhancement of export resilience critical for China to stabilize foreign trade and safeguard economic security. As the foundational underpinning of the Digital China initiative, digital infrastructure supported a digital economy worth 53.9 trillion yuan in China in 2023, accounting for 42.8% of GDP. New infrastructure such as 5G, broadband and industrial internet effectively cuts cross-border transaction costs and expands overseas markets, serving as a vital buffer against external trade risks. While provincial governments have ramped up investment in digital infrastructure, wide disparities exist in regional construction standards and digital application ecosystems. Systematic verification is still needed regarding the impact mechanisms of digital infrastructure on export resilience and its heterogeneous regional effects, which motivates this study.[1]

Theoretically, existing literature mostly examines the economic effects of digital infrastructure or determinants of export resilience in isolation, with few integrated analytical frameworks covering both dimensions. Drawing on transaction cost theory, resilience theory and new economic geography, this paper sorts out transmission logic through two channels: supply chain flexibility and openness, enriching research on digital trade and open economies. Practically, its empirical findings provide evidence for provincial authorities to coordinate digital infrastructure deployment, prevent inefficient investment that prioritizes hardware over practical application, and advance high-quality development of foreign trade.[2]

This paper consists of six chapters and adopts three research methods: literature review, theoretical analysis and empirical research. Based on panel data of 30 Chinese provinces from 2010 to 2023, it constructs a comprehensive digital infrastructure index via the entropy method and measures export resilience using the deviation method. A two-way fixed-effects baseline model is established, combined with Bootstrap mediation tests to identify internal mechanisms, interaction terms for heterogeneity analysis, and strategies including lagged core variables and exclusion of municipalities to mitigate endogeneity and verify robustness.

This study has three innovations: first, it integrates digital infrastructure development and export resilience into a unified analytical framework; second, it disentangles two transmission paths from supply and demand sides, namely supply chain flexibility and openness; third, it introduces grouping by e-commerce activity to verify that the effectiveness of digital infrastructure relies on mature local digital ecosystems. Meanwhile, this research has limitations: Xizang is excluded due to data constraints, the dataset only covers up to 2023, and linear interpolation for missing values may bring minor errors.[3] The export resilience indicator mainly captures post-shock recovery rather than shock resistance and structural adaptability, and the analysis is limited to provincial macro data without further exploration of industrial and firm-level heterogeneity.

2. Theoretical Mechanisms and Research Hypotheses

2.1. Theoretical Foundations

2.1.1. Transaction Cost Theory

Transaction cost theory holds that market transactions are not cost-free. Conducting a transaction incurs various expenses including information searching, negotiation, contract signing, performance supervision and default handling, which are collectively referred to as transaction costs. Later, Williamson and other scholars further developed this theory, dividing transaction costs into ex ante costs (such as information search, bargaining and contract formulation) and ex post costs (such as supervision, implementation and dispute resolution). They also pointed out that the magnitude of transaction costs is affected by bounded rationality, asset specificity, uncertainty, information asymmetry and transaction frequency.

2.1.2. Resilience Theory

Originating from ecology, resilience theory describes the capacity of ecosystems to preserve their fundamental structures, functions and feedback mechanisms when subjected to external disturbances such as wildfires and droughts. It has since been widely applied to sociology, economics, urban planning and other disciplines. The theory stresses that resilience encompasses not only a system’s ability to withstand shocks or recover rapidly, but also its potential to learn, adjust and restructure itself to tackle future uncertainties.

In economic and trade research, resilience is commonly adopted to analyze the stability and adaptability of national or regional export systems, industrial chains and digital infrastructure amid shocks including global supply chain disruptions, geopolitical conflicts, natural disasters and technological changes. Highly resilient systems generally feature diversity, redundancy, modularity, self-organization and rapid response mechanisms.

2.1.3. New Economic Geography

This theory highlights that the spatial agglomeration of economic activities is shaped not merely by traditional factor endowments, but more importantly by the interaction of increasing returns to scale, transportation costs and factor mobility. Against the backdrop of the digital economy, digital infrastructure drastically reduces the "virtual distance" for information transmission and transactions, substituting or cutting down conventional transportation costs, thereby reshaping firms’ location choices and the layout of export networks.

2.2. Mechanism Analysis of Digital Infrastructure’s Impact on Export Resilience

2.2.1. Direct Effect: Reduction of Transaction Costs

Digital infrastructure directly strengthens enterprises’ capacity to cope with external shocks by cutting transaction costs including information search, negotiation, contract performance and cross-border coordination. High-speed networks, data interconnection and intelligent services shorten decision-making response time and improve the stability and predictability of export activities. Accordingly, it exerts a significant positive effect on export resilience without relying on intermediary channels.

H1: A higher level of digital infrastructure construction corresponds to stronger provincial export resilience.

2.2.2. Supply-side Effect: Improvement of Supply Chain Flexibility

Sound digital infrastructure, such as high-speed networks, industrial internet and intelligent logistics systems, empowers enterprises to realize flexible production and industrial chain collaboration, and reduces coordination costs. It also boosts the proportion of high-tech products in total exports. Generally, high-tech products feature strong non-substitutability, high added value and stable international demand, which helps the supply chain better adapt to and recover from external shocks.

H2: Digital infrastructure enhances export resilience by improving supply chain flexibility.

2.2.3. Supply-side Effect: Improvement of Supply Chain Flexibility

Digital infrastructure elevates the degree of opening-up (measured by the ratio of total import and export volume to GDP), lowers the costs for enterprises to enter the international market, and promotes the diversification of export markets. When one overseas market is hit by shocks, enterprises can swiftly shift to other destinations to diversify demand risks, thereby strengthening export resilience. This mechanism reflects the risk buffering function of digital infrastructure on the demand side.

H3: Digital infrastructure improves export resilience by raising the degree of opening-up.

2.3. Design of Heterogeneity Analysis

2.3.1. Grouping Based on Development Disparities between Eastern, Central and Western Regions

To explore whether the impact of digital infrastructure on export resilience presents regional heterogeneity, this paper divides the samples into two groups: the eastern region and the central and western regions according to regional economic development levels.[4]

2.3.2. Grouping Based on Regional E-commerce Activity

To verify whether the influence of digital infrastructure on export resilience depends on the maturity of the local digital economy ecosystem, this paper classifies the samples into high and low e-commerce activity groups for heterogeneity analysis, with the number of enterprises engaged in e-commerce transactions in each province as the grouping criterion.[5]

The indicator number of enterprises engaged in e-commerce from the China Statistical Yearbook is adopted. Taking the national median as the threshold, provinces with values above the median are categorized as the high e-commerce activity group, while those at or below the median are classified as the low e-commerce activity group.

The number of e-commerce enterprises not only reflects the application scope of digital technologies, but also represents the supporting capabilities of regions in cross-border marketing, intelligent logistics, payment and settlement. Without active market players and a sophisticated digital service system, sound hardware facilities alone cannot translate digital infrastructure into tangible foreign trade competitiveness.[6]

3. Research Design

3.1. Sample Selection and Data Sources

This paper uses panel data of 30 provincial-level regions in China (excluding Xizang) from 2010 to 2023 as the research sample. The data are sourced from provincial statistical yearbooks, China Statistical Yearbook, the Ministry of Industry and Information Technology, and the General Administration of Customs.

3.2. Variable Definition and Measurement

Explained Variable: Export Resilience (Res). Referring to the methodology proposed by He Canfei and Chen Tao, this study measures export resilience. Taking the financial crisis as an exogenous shock, export resilience of each province is reflected by the deviation degree of provincial export volume during 2010–2023 relative to the export volume in 2008. The calculation formula is presented as follows:

$$Res_{it}=\frac{\mathrm{export_{it}}-\mathrm{export_{i2008}}}{export_{i2008}}$$

Explanatory Variable: Digital Infrastructure Level (Diginfra).This paper adopts the comprehensive indicator system method to measure the development level of digital infrastructure across provinces. Following the research frameworks of Zhao Xing and Wang Qin et al. , representative indicators are selected from the two dimensions of input and output of digital infrastructure to establish a comprehensive evaluation system. The entropy weight method is applied to calculate indicator weights and obtain the final scores. The specific measurement methods are shown in Table 1.

Table 1. Indicator Measurement Methods

Explanatory Variable	Primary Indicator	Secondary Indicator
Digital Infrastructure (DigInfrait)	Input of Digital Infrastructure	Density of long-distance optical cables
		Per capita internet access ports
		Proportion of employees in related industries
	Output of Digital Infrastructure	Per capita telecommunications business volume
		Mobile phone penetration rate
		Internet penetration rate

Referring to Wang Xiaolong, this study measures the degree of opening-up by the sum of export orientation ratio and import penetration ratio, namely the proportion of total imports and exports in regional gross domestic product.The supply chain flexibility in this paper focuses on supply flexibility, logistics flexibility and operational flexibility of high-tech product exports. Therefore, the export volume of high-tech products is adopted to quantify this indicator, defined as the export intensity of high-tech products, which is calculated as the ratio of high-tech product exports to total exports.

3.3. Econometric Model Specification

3.3.1. Benchmark Regression Model

$$Res_{it} = \alpha + \beta Diginfra_{it} + \gamma Control_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where Res_i denotes export resilience, $Diginfra_i$ represents the development level of digital infrastructure, and $Control_{it}$ stands for control variables. μ_i and λ_t refer to province fixed effects and year fixed effects respectively, while ε_{it} is the random error term. Standard errors are clustered at the provincial level.

3.3.2. Mediation Effect Identification: Bootstrap Method and Indirect Effect Test

To identify the internal mechanism through which digital infrastructure affects export resilience, this paper adopts the mediation effect model for empirical testing. Following the suggestions of Preacher and Hayes and Jiang Ting, this study does not judge the existence of mediation effect merely based on the Sobel test or the individual significance of path coefficients. Instead, it directly estimates the indirect effect and its confidence interval via the Bootstrap sampling method.

Specifically, the two-stage regression models are constructed as follows:

$$M_i = a_0 + a_1 Diginfra_i + \gamma Control_i + \mathcal{E}_{1i}$$

$$Res_i = \beta_0 + \beta_1 Diginfra_i + \beta_2 M_i + \delta Control_i + \mu_i + \lambda_t + \varepsilon_{2i}$$

Where Res_i refers to export resilience, $Diginfra_i$ denotes the level of digital infrastructure construction, M_i stands for the mediating variable, and $Control_{it}$ represents the set of control variables. μ_i and λ_t are province fixed effects and year fixed effects respectively, and ε_{it} is the random error term. Standard errors are clustered at the provincial level.

The indirect effect is defined as $a_1\beta_2$. Given the within-group correlation existing in provincial panel data, this paper applies the Bootstrap method with clustering at the provincial level and conducts 5,000 repeated samplings. We report the Bias-Corrected Confidence Interval (BC CI). If the interval does not contain zero, the mediation effect is deemed statistically significant at the 5% significance level.

3.3.3. Heterogeneity Test Model

$$Res_{it} = \alpha + \beta_1 Diginfra_{it} + \beta_2 (Diginfra_{it} \times D_i) + \gamma Control_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where Res_i denotes export resilience, $Diginfra_i$ represents the level of digital infrastructure construction, and D_i is the grouping dummy variable. $Control_{it}$ refers to control variables. β_1 stands for the effect of the benchmark group, while($\beta_1 + \beta_2$)indicates the effect of the treatment group. μ_i and λ_t are province fixed effects and year fixed effects respectively, and ε_{it} is the random error term. Standard errors are clustered at the provincial level.

3.4. Robustness and Endogeneity Treatment

3.4.1. Endogeneity Treatment Strategy: Lagged Term Approach

Considering the potential reverse causality between digital infrastructure and export resilience — regions with sound export performance may receive more investment in digital sectors — this paper adopts the digital infrastructure indicator lagged by one period as the core explanatory variable to mitigate potential endogeneity issues.

3.4.2. Robustness Test: Sample Exclusion

Exclude the data of municipalities directly under the Central Government to adjust the sample scope.

4. Empirical Results and Analysis

4.1. Descriptive Statistics

The dataset consists of 420 observations. The descriptive statistics of major variables are presented in the table below. The explained variable Res (export resilience) has a mean value of 1.523, a standard deviation of 2.109, a minimum of -0.735 and a maximum of 12.982. This indicates notable disparities in export recovery capacity across regions after external shocks, and some samples show strong resilience.

The core explanatory variable Diginfra (digital infrastructure level) has a mean of 8.464 and a standard deviation of 2.253, with a relatively concentrated distribution. It suggests that although digital infrastructure development varies across prefecture-level cities in China, the overall level keeps improving steadily.

Among the control variables: Lnfin (local fiscal expenditure) averages 8.409 and Mark (marketization index) averages 8.003. Their relatively high means and moderate fluctuations reveal that the sampled regions have sound fiscal capacity and active foreign trade. Upg (industrial upgrading) has a mean of 1.262 with a small standard deviation, implying a steady progress of industrial transformation and upgrading. The mean of Gfdi (foreign direct investment) is 0.200, which reflects that the overall scale of foreign capital inflow is modest with prominent regional differences. Fd (financial development level) records a mean of 1.512 and a standard deviation of 0.450, demonstrating a balanced distribution of financial development across regions.

Overall, the mean values and standard deviations of all variables fall within a reasonable range, and no extreme outliers are observed. The data is of good quality and suitable for subsequent regression analysis. The specific measurement methods are shown in Table 2.

Table 2. Results of Descriptive Statistics

Variable	N	mean	sd	min	max
Res	420	1.523	2.109	-0.735	12.982
Diginfra	420	8.464	2.253	3.375	15.765
Lnfin	420	8.409	0.633	6.323	9.827
Mark	420	8.003	1.939	3.359	11.494
Upg	420	1.262	0.735	0.499	5.689
Gfdi	420	0.020	0.020	0.000	0.120
Fd	420	1.512	0.450	0.670	2.774

4.2. Descriptive Statistics

To test for multicollinearity among variables, this paper conducts the Variance Inflation Factor (VIF) test. The results show that the VIF values of all variables are below 5, with an average VIF of 1.95. This suggests there is no severe multicollinearity in the model, and the regression results are robust and reliable.The Hausman Test is performed to determine the appropriate model specification. The null hypothesis H0 assumes that individual effects are uncorrelated with explanatory variables, supporting the adoption of the random effects model. The alternative hypothesis H1 holds that individual effects are correlated with explanatory variables, indicating the fixed effects model should be applied. The test yields a p-value of 0.000, which is significantly lower than the significance level of 0.05. Accordingly, the null hypothesis is rejected, proving a significant correlation between individual effects and explanatory variables. Therefore, the fixed effects model is adopted for subsequent regression analysis to avoid estimation bias and guarantee consistent parameter estimates. The specific measurement methods are shown in Table 3 and Table 4.

Table 3. Multicollinearity Test of Samples

Variable	VIF	1/VIF
Mark	2.68	0.372453
Diginfra	2.58	0.386850
Upg	2.02	0.495102
Lnfin	1.85	0.541302
Gfdi	1.51	0.662289
Fd	1.08	0.925976
Mean VIF	1.95	

Table 4. Hausman Test Results

H_0	Individual effects are uncorrelated with explanatory variables: random effects model applies.
H_1	Individual effects are correlated with explanatory variables: fixed effects model applies.
P-value	0.000

4.3. Benchmark Regression Analysis

This paper employs the fixed effects model to empirically examine the relationship between digital infrastructure level (Diginfra) and export resilience (Res). Six sets of regression results are presented by gradually adding control variables to improve estimation robustness.

The results show that the coefficient of the core explanatory variable Diginfra remains positive and statistically significant at the 1% level across all models. This indicates that a higher level of digital infrastructure corresponds to stronger provincial export resilience. As control variables are added sequentially, the coefficient declines from 0.384 to 0.190 while staying statistically significant. It suggests that even after controlling for local fiscal expenditure (Lnfin), marketization index (Mark), industrial structure upgrading (Upg), foreign direct investment (Gfdi) and financial development (Fd), digital infrastructure still exerts an independent positive effect on export resilience. This verifies Hypothesis H1: digital infrastructure is a key driving force for improving export resilience.

Next is the analysis of control variables. Lnfin (local fiscal expenditure) is significantly positive in all models, implying that fiscal expenditure helps strengthen regional capacity to cope with external shocks. Mark (marketization index) is significantly negative in the first two columns but turns insignificant in subsequent models. Regions with a high degree of marketization generally feature concentrated investment in the digital economy and human capital. Their positive impact on export resilience is partially captured by digital infrastructure and human capital, which weakens the independent explanatory power and marginal effect of marketization.

In addition, year and province fixed effects are included in all models to control for time trends and regional heterogeneity. The R-squared value rises steadily from 0.413 to 0.455, which means the model's explanatory power improves with the inclusion of more variables. Overall, the regression results are robust. Digital infrastructure enhances the risk resistance and recovery capacity of regional export systems by reducing transaction costs, improving information transparency and strengthening supply chain collaboration. The specific measurement methods are shown in Table 5.

Table 5. Benchmark Regression Results

Variable	(1) Res	(2) Res	(3) Res	(4) Res	(5) Res	(6) Res
Diginfra	0.384***	0.428**	0.431**	0.419**	0.323**	0.190**
	(3.74)	(2.16)	(2.19)	(2.27)	(2.19)	(2.17)
Lnfin		3.303***	3.425***	3.373***	3.966***	3.949***
		(3.31)	(3.17)	(3.01)	(2.98)	(2.88)
Mark			-0.0667	-0.0828	-0.0370	-0.0368
			(-0.25)	(-0.32)	(-0.14)	(-0.14)
Upg				-0.187	-0.150	-0.142
				(-0.44)	(-0.35)	(-0.33)
Gfdi					-7.959	-7.894
					(-1.53)	(-1.49)
Fd						0.046
						(-0.22)
-cons	-2.124***	-27.73***	-28.20***	-27.55***	-32.18***	-32.17***
	(-3.47)	(-3.58)	(-3.60)	(-3.33)	(-3.26)	(-3.24)
year fe	YES	YES	YES	YES	YES	YES
province fe	YES	YES	YES	YES	YES	YES
R^2	0.413	0.449	0.449	0.450	0.455	0.455
observations	418	418	418	418	418	418

Note: Figures in parentheses are cluster-robust t-statistics at the provincial level. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

4.4. Mediation Mechanism Test

Table 6. Mediation Test Results

Variable	(1) Open	(2) Res	(3) Res	(4) Tkng	Variable
Diginfra	0.028**	0.244	0.316*	0.028**	Diginfra
	(1.92)	(1.56)	(2.01)	(2.26)	
Open		6.466***	4.576*		Tkng
		(4.31)	(1.99)		
Lnfin	-0.167***	5.029***	4.044***	-0.106	Lnfin
	(-2.71)	(3.8)	(3.54)	(-0.95)	
Mark	0.016	-0.146	-1.131	0.027	Mark
	(1.3)	(-0.62)	(-0.61)	(1.33)	
Upg	-0.084	0.405	-0.120	-0.052	Upg
	(-1.44)	(1.32)	(-0.31)	(-1.47)	
Gfdi	-1.214	-0.037	-7.932*	-0.094	Gfdi
	(-1.7)	(-0.01)	(-1.69)	(-0.27)	
Fd	-0.006	0.089	0.081	0.001	Fd
	(-0.037)	(0.51)	(0.50)	(0.13)	
-cons	1.426***	-41.393***	-32.138***	0.625***	-cons
	(2.81)	(-4.17)	(-3.67)	(0.86)	
year fe	YES	YES	YES	YES	Year FE
province fe	YES	YES	YES	YES	Province FE
R^2	0.365	0.534	0.492	0.332	R^2
observations	418	418	418	418	Observations

Note: Figures in parentheses are province-clustered t-statistics. *, ** and *** indicate significance at the 10%, 5% and 1% levels respectively.

Table 7. Bootstrap Mediation Test Results of Tkng

	effect size	95% confidence interval (BC) lower limit	 upper limit	Boot SE	relative effect size
direct effect	0.3167	0.1146	0.5355	0.1059	71%
indirect effect	0.1287	0.0314	0.2732	0.0624	29%
total effect	0.4454				

Table 8. Bootstrap Mediation Test Results of Open

	effect size	95% confidence interval (BC) lower limit	 upper limit	Boot SE	relative effect size
direct effect	0.2442	0.0561	0.4588	0.1022	57%
indirect effect	0.1851	0.0744	0.3191	0.0628	43%
total effect	0.4293				

This paper applies the Bootstrap method to examine the mediation mechanisms of digital infrastructure development on China's export resilience. The results reveal that digital infrastructure exerts an indirect impact through two pathways: improving supply chain flexibility (Tkng) and expanding the degree of opening-up (Open). The specific measurement methods are shown in Table 6, table 7 and table 8.

The mediation effect of supply chain flexibility is 0.1287, with the 95% bias-corrected confidence interval ranging from 0.0314 to 0.2732, and its contribution rate is 29%. This indicates that supply chain flexibility plays a significant mediating role in the process where digital infrastructure boosts export resilience, so Hypothesis 2 is valid. The mediation effect of the degree of opening-up is 0.1851, with a 95% bias-corrected confidence interval of [0.0744, 0.3192] and a contribution rate of 43%. It suggests that the degree of opening-up acts as a more critical mediating variable, verifying Hypothesis 3 that digital infrastructure enhances export resilience by raising the level of opening-up.

4.5. Heterogeneity Analysis

4.5.1. Regional Heterogeneity

Table 9. Heterogeneity Regression: Eastern, Central and Western Regions

	(1) full sample benchmark Res	(2) interaction term model Res
Diginfra	0.190**	0.547***
	(2.17)	(2.95)
Diginfra×East		-0.499***
		(-3.54)
control variables	control	control
year fe	YES	YES
province fe	YES	YES
R^2	0.455	0.455
observations	418	418

Note: Figures in parentheses are province-clustered t-statistics. *, ** and *** denote significance at the 10%, 5% and 1% levels respectively.

The regression results of the interaction term model show that the coefficient of the interaction between digital infrastructure and the dummy variable for the eastern region is -0.499, which is highly significant at the 1% statistical level. This reveals that the impact of digital infrastructure on export resilience differs substantially between the eastern region and the central and western regions. The specific measurement methods are shown in Table 9.

Given that the central and western regions serve as the benchmark group in the model, the coefficient of the core variable Diginfra represents its marginal effect in central and western areas. The total effect for the eastern region is 0.547 + (−0.499) = 0.048, which proves statistically insignificant according to the linear combination test.

The findings indicate that the enabling effect of digital infrastructure is more pronounced in central and western regions, while it weakens remarkably and even approaches saturation in the eastern region.

4.5.2. Heterogeneity Analysis of Regional E-commerce Activity

Table 10. Heterogeneity Analysis of Regions with High and Low E-commerce Activity

	(1) full sample benchmark Res	(2) interaction term model Res
Diginfra	0.190**	-0.193
	(2.17)	(-0.76)
High-EC		-4.220
		(-2.13)
Diginfra×High-EC		0.699***
		(2.77)
control variables	control	control
year fe	YES	YES
province fe	YES	YES
R^2	0.455	0.455
observations	418	418

Note: Figures in parentheses are province-clustered t-statistics. *, ** and *** indicate significance at the 10%, 5% and 1% levels respectively.

The results show that the marginal effect of digital infrastructure on export resilience is insignificant in regions with low e-commerce activitβ_1y (=-0.193, p = 0.454). It suggests that digital infrastructure can hardly translate into stable trade performance without digital practices among market participants. On the contrary, the facilitating effect becomes significantly stronger in regions with high e-commerce activity (β_2=0.699, p = 0.010), demonstrating that the value of digital technologies is highly dependent on the maturity of local digital ecosystems. The specific measurement methods are shown in Table 10.

Notably, the baseline export resilience of high e-commerce activity regions is markedly lower than that of low-activity regions (β_1=-4.221, p = 0.042). This may be attributed to their more sophisticated export structure, a larger share of small and medium-sized enterprises, and heavy reliance on external markets, which lead to inherently greater volatility. The interaction term presents a significant positive effect of digital infrastructure on export resilience in such regions (p = 0.010). This indicates that digital technologies do not merely benefit advantaged areas, but act as a more powerful stabilizer amid challenging operating environments.

4.6. Robustness Test

4.6.1. One-period Lag Treatment

The results indicate that after incorporating control variables, the coefficient of Diginfra_{t-1} remains significantly positive across all models and ranges steadily from 0.290 to 0.309. This reveals that the promoting effect of digital infrastructure on export resilience features a time lag, which supports the causal logic that investment in digital infrastructure precedes the improvement of export resilience. In addition, financial development exerts a persistent and significantly positive impact on export resilience, demonstrating that financial resources serve as an important pillar for trade stability. The specific measurement methods are shown in Table 11.

Table 11. One-period Lag Benchmark Regression Results

Variable	(1) Res	(2) Res	(3) Res	(4) Res	(5) Res	(6) Res
Diginfra	0.304***	0.303*	0.308*	0.309*	0.296*	0.290*
	(2.89)	(1.77)	(1.83)	(1.89)	(1.82)	(1.81)
Lnfin		2.652**	2.828**	2.818**	3.487**	3.501**
		(2.30)	(2.27)	(2.21)	(2.24)	(2.21)
Mark			-0.09	-0.098	-0.053	-0.053
			(-0.37)	(-0.40)	(-0.21)	(-0.21)
Upg				-0.040	-0.003	-0.007
				(-0.09)	(-0.01)	(-0.02)
Gfdi					-8.606	-8.653
					(-1.54)	(-1.53)
Fd						-0.041
						(-0.21)
-cons	-1.22**	-22.21**	-22.96**	-22.82**	-28.17**	-28.19**
	(-1.98)	(-3.45)	(-3.48)	(-2.37)	(-2.38)	(-2.37)
year fe	YES	YES	YES	YES	YES	YES
province fe	YES	YES	YES	YES	YES	YES
R^2	0.386	0.411	0.412	0.412	0.419	0.419
observations	390	390	390	390	390	390

Note: Values in parentheses are province-clustered t-statistics. *, ** and *** denote significance at the 10%, 5% and 1% levels respectively.

4.6.2. Change of Sample Scope

The results show that after excluding municipalities directly under the Central Government, the coefficient of the core explanatory variable Diginfra remains positive and significant at the 1% or 5% level in all models. Its estimated value gradually decreases from 0.484 to 0.463 and stays at a relatively high level, indicating that digital infrastructure development exerts a sustained and robust positive effect on export resilience. This finding further verifies the reliability of the baseline regression results. It suggests that the conclusions are not driven by distinctive factors such as high industrial agglomeration and strong policy support in municipalities, and also hold true for ordinary prefecture-level cities.[7]

Overall, the regression results after removing the samples of municipalities are highly consistent with the baseline results. There are no fundamental changes in the sign, magnitude and significance of the core variable coefficients, which further confirms the general applicability and robustness of digital infrastructure in improving export resilience. The specific measurement methods are shown in Table 12.

Table 12. Benchmark Regression Results after Sample Exclusion

Variables	(1) Res	(2) Res	(3) Res	(4) Res	(5) Res	(6) Res
Diginfra	0.484***	0.504**	0.520**	0.499**	0.462**	0.463**
	(4.24)	(2.28)	(2.42)	(2.40)	(2.40)	(2.20)
Lnfin		3.976***	4.141***	4.298***	4.871***	4.869***
		(3.23)	(3.17)	(3.30)	(3.30)	(3.07)
Mark			-0.131	-0.0917	-0.054	-0.0546
			(-0.45)	(-0.32)	(-0.19)	(-0.19)
Upg				-0.494	0.546	0.547
				(1.01)	(1.12)	(1.14)
Gfdi					-8.488	-8.490
					(-1.40)	(-1.41)
Fd						0.005
						(-0.03)
-cons	-2.438***	-33.06***	-33.53***	-35.26***	-32.18***	-32.17***
	(-3.87)	(-3.45)	(-3.48)	(-3.59)	(-3.26)	(-3.24)
year fe	YES	YES	YES	YES	YES	YES
province fe	YES	YES	YES	YES	YES	YES
R^2	0.454	0.503	0.505	0.508	0.514	0.514
observations	364	364	364	364	364	364

Note: Figures in parentheses are province-clustered t-statistics. *, ** and *** represent significance at the 10%, 5% and 1% levels, respectively.

5. Conclusions and Policy Implications

5.1. Main Research Conclusions

The improvement of digital infrastructure significantly enhances provincial export resilience, which verifies Hypothesis H1. Trade facilitation and supply chain flexibility serve as two major transmission channels, supporting Hypotheses H2 and H3. The export-stabilizing effect of digital infrastructure is not evenly distributed and largely depends on the digital application capacity of local market entities. Specifically, digital infrastructure can effectively boost export resilience only in regions with a high concentration of e-commerce enterprises.

5.2. Policy Implications

Digital infrastructure should be placed at the core of the strategy for foreign trade resilience. Policies shall shift from prioritizing construction over application to the coordinated development of infrastructure and digital ecosystems. [8] Central and western regions need to improve digital foundations and foster market participants, while the eastern regions shall further integrate digital technologies with foreign trade. Meanwhile, governments should cooperate with platform enterprises to optimize cross-border digital services and cut institutional costs, so as to fully unlock the potential of digital infrastructure in stabilizing foreign trade.

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