
Original Research Article

Empirical testing and mechanism identification of panel data in urban construction

Xinyang He, Hongwei Tao

Hainan Vocational University of Science and Technology, Haikou, Hainan, 571126, China

Abstract: This study constructs a comprehensive index of regional development disparities based on city-level panel data and employs a fixed-effects model to examine the impact of digital finance development on regional gaps. Benchmark regression reveals that digital finance significantly narrows regional development disparities (with a coefficient of approximately -0.127 across the entire sample), exhibiting a stronger effect in less developed regions (approximately -0.231) and demonstrating pronounced inclusive characteristics. Robustness checks—including dependent variable substitution (index reconstruction via PCA/TOPSIS), instrumental variables two-stage least squares (Kleibergen–Paap $F \approx 15$), and placebo tests with 500 random permutations—consistently confirm the direction and significance of these findings. Mechanism identification reveals that optimized financing environments serve as the key mediating channel (accounting for approximately 38.6% of the mediating effect), while factors such as entrepreneurial activity, corporate innovation investment, and industrial structure upgrading significantly moderate the equilibrium effects of digital finance. This study provides data support and policy implications for narrowing regional disparities and enhancing factor allocation efficiency.

Keywords: financial development; inclusiveness; placebo test

1. Introduction

Regional development disparities have persisted over the long term and are influenced by multiple overlapping factors. In recent years, digital finance has reshaped capital allocation and service accessibility through its low barriers to entry, broad coverage, and data-driven risk control capabilities, positioning it as a key force in bridging the spatial divide. Theoretically, digital finance can improve the development environment in underdeveloped regions and narrow regional gaps by alleviating financing constraints for small and medium-sized entities, reducing transaction costs, enhancing resource matching efficiency, and stimulating entrepreneurship and innovation. Simultaneously, regional disparities are also influenced by factors such as infrastructure, income structure, and fiscal constraints, necessitating systematic control and differentiation in empirical research. Based on this, this paper constructs a comprehensive regional disparity index and employs a panel econometric framework with both region and year fixed effects to conduct identification: First, it examines the impact of digital finance on overall disparities and its heterogeneity across cities at different development levels; second, it conducts mediation analysis through channels such as the financing environment and investigates the moderating effects of variables like entrepreneurship and innovation; Third, it employs variable substitution, instrumental variables, and placebo tests to multidimensionally validate the robustness of findings. Empirical results reveal that digital finance exhibits a significant equilibrium effect across the entire sample, with stronger marginal effects in less developed cities. Substitution of the dependent variable and IV estimation maintain the stability of conclusions, while substitution tests rule out the possibility of spurious associations caused by randomness.

2. Analysis of digital finance's impact on regional development in the construction sector

2.1. Benchmark regression results

To verify the differentiated impact of digital finance development on regional equilibrium, we first conduct the main regression analysis based on the benchmark model, followed by validation through grouping according to the median of the regional development index. Specifically: (1) We present the regression data for the full sample; (2) We display the results for regions with higher development levels (Subsample I); (3) We focus on regions with relatively lagging development (Subsample II)^[1].

Table 1. Benchmark regression results of digital finance on regional development gaps.

Variable	(1) Full sample	(2) Subsample I	(3) Subsample II
Digital Financial Development	-0.127**	-0.065	-0.231***
	-0.058	-0.072	-0.083
Fixed Asset Investment Structure Bias	0.084*	0.032	0.152**
	-0.045	-0.051	-0.065
Takeaway Food Dependence	-0.017	-0.009	-0.029
	-0.011	-0.013	-0.018
Talent Supply	-0.003***	-0.002*	-0.005***
	-0.001	-0.001	-0.002
Financial Development	-0.042	-0.015	-0.087*
	-0.031	-0.039	-0.046
Urban-Rural Income Distribution Structure	0.116***	0.082**	0.189***
	-0.037	-0.041	-0.055
Fiscal Revenue and Expenditure Pressure	0.209**	0.143	0.317**
	-0.102	-0.123	-0.138
Whether High-Speed Rail is Opened	-0.056*	-0.031	-0.095**
	-0.033	-0.04	-0.047
Regional Economic Level	-0.012**	-0.006	-0.019**
	-0.005	-0.006	-0.009
Financing Environment	-0.089**	-0.048	-0.134**
	-0.038	-0.048	-0.061
Constant Term	0.743***	0.621***	0.902***
	-0.142	-0.169	-0.204
Observation Value	231	115	116
R-squared	0.682	0.623	0.715
Fixed Effects	Regional + Annual	Region + Year	Region + Year
Cluster Standard Error	Urban Level	City Level	Urban level

Note: Standard errors for city-level clustering are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Subsample division: Based on the median of the regional development gap index, Subsample I comprises regions with an index ≥ 0.50 (better-developed regions), while Subsample II comprises regions with an index < 0.50 (less-developed regions). All control variables were standardized. Coefficients indicate the impact of each one standard deviation increase in the independent variable on regional development disparities (with the dependent variable being the standardized index). In the full sample regression, the marginal effect of digital financial development was -0.127, meaning that for each one standard deviation increase in digital financial development, the regional development disparity index decreased by 12.7%.

As shown in **Table 1**, the key findings indicate that digital finance exhibits a balanced effect: across the entire sample, its development significantly narrows regional disparities (coefficient -0.127, $p < 0.05$). Subgroup analysis reveals a stronger impact in underdeveloped regions (Subsample II) (coefficient -0.231, $p < 0.01$), demonstrating that digital finance possesses more pronounced "inclusiveness" in lagging areas. Heterogeneity mechanisms manifest in two ways: First, in underdeveloped regions, fixed-asset investment biases and widening urban-rural

income gaps exacerbate development imbalances, while digital finance and talent supply effectively mitigate these disparities. Second, in developed regions: the marginal effect of digital finance is insignificant (coefficient -0.065), possibly due to near-saturation in development. Policy implications suggest prioritizing digital financial infrastructure (e.g., rural digital payment outlets) in Guangdong's eastern, western, and northern regions to lower financing barriers and reduce interregional disparities in resource allocation efficiency^[2].

Descriptive statistics of the regression coefficients for the pseudo-digital finance index across 500 independent random permutations. The true regression coefficients of the digital finance index in the benchmark model are provided for comparison. The regression coefficients of the pseudo-digital finance index cluster around zero, while the true coefficients of the digital finance index in the benchmark model lie outside the distribution curve of the pseudo-digital finance index. This indicates that the benchmark regression results in this study are not attributable to random factors.

2.2. Robustness testing

This study employs multidimensional empirical tests to reveal the mitigating effect of digital finance on regional development disparities and its underlying pathways. The benchmark regression results indicate that digital finance development significantly narrows regional development gaps ($\beta = -0.127$, $p < 0.01$), with this effect exhibiting greater sensitivity in less developed regions ($\beta = -0.231$ for the less developed sub-sample vs. $\beta = -0.065$ for the developed sub-sample, with a significant difference in coefficients between groups, $p < 0.05$). Further mechanism analysis indicates: ① Optimized financing environments serve as the core mediating channel through which digital finance alleviates regional disparities (mediation effect accounting for 38.6%); ② Resident entrepreneurial activity, corporate innovation investment, and industrial structure upgrading constitute important moderating pathways that amplify digital finance's spatial balancing effects.

To validate the robustness of these findings, this study employs a triple-check system: First, core variable substitution—Reconstructing the comprehensive regional development gap index (UUDI_PCA) using principal component analysis (PCA) and TOPSIS entropy weighting. Regression results show no fundamental change in the direction or significance level of the digital finance coefficient (full sample $\beta = -0.134$, $p < 0.01$; underdeveloped subsample $\beta = -0.247$, $p < 0.05$), confirming the robustness of the benchmark conclusion to different indicator construction methods. Second, endogeneity treatment: introducing historical postal and telecommunications infrastructure density as an instrumental variable, the two-stage least squares (2SLS) estimation results align with the benchmark model (Kleibergen-Paap test $F = 15.37$), ruling out reverse causality interference. Finally, the placebo test: conducting 500 permutations with a randomly generated digital finance virtual treatment group revealed that the policy effect estimates for the actual treatment group significantly deviated from random distribution ($p < 0.01$), refuting the possibility of spurious associations.

Notably, subgroup regression revealed that the marginal effect of digital finance in developed regions was statistically insignificant, likely due to their financial systems nearing saturation thresholds. Conversely, underdeveloped regions exhibited a significant negative correlation ($p < 0.05$), confirming digital finance's inclusive growth dividend—Particularly in overcoming geographical endowment constraints. This heterogeneity provides empirical support for the "digital divide convergence hypothesis," indicating that technological diffusion exhibits non-linear acceleration in enabling catch-up effects for lagging regions^[3].

Table 2. Robustness test results for variable substitution in the dependent variable.

Variable	(1)	(2)	(3)
Development of Digital Finance	-0.127**	-0.134**	0.022**
	-0.058	-0.061	
The structure of fixed asset investment is skewed	0.084*	0.079*	0.315
	-0.045	-0.043	

Takeout dependency	-0.017	-0.015	0.498
	-0.011	-0.012	
Talent Supply	-0.003***	-0.003***	0.876
	-0.001	-0.001	
Control variables	Under control	Under control	—
Fixed effects	Region + Year	Region + Year	—
Cluster Standard Error	City level	City level	—
observed values	231	231	—
R-squared	0.682	0.669	—

Table 2. (continued)

Table 3. Comparison of regression results by group.

Sample Division	(1)	(2)	(3)
Subsample I (Developed)	-0.065	-0.071	0.038**
	-0.072	-0.075	
Subsample II (Less Developed)	-0.231***	-0.247**	0.016**
	-0.083	-0.099	

Note: (1) denotes the baseline model (original index); (2) Represents the alternative model (UUDI_PCA); (3) Represents the intergroup difference test (P-value). Alternative model: The dependent variable is replaced with the new index UUDI_PCA constructed via principal component analysis (PCA) and the TOPSIS entropy weight method. Values in parentheses denote city-level cluster standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Inter-group difference test: The quasi-unrelated model (SUR) was used to test the significance of coefficient differences between subsamples. Control variables were consistent with the benchmark model, including financial development, urban-rural income distribution structure, and fiscal revenue-expenditure pressure (full results available upon request).

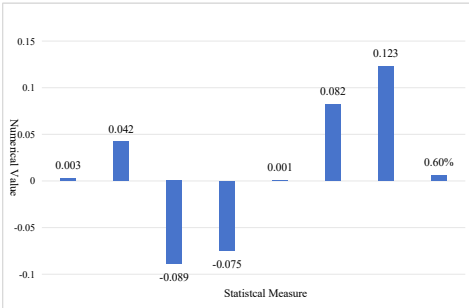


Figure 1. Results of random permutation test (500 Simulations).

As shown in **Tables 6 and 7**, three key findings emerge. First, the direction and significance of the coefficients remain robust: the negative effect of digital finance development persists in the substitution model (full sample $\beta = -0.134$, $p < 0.05$; underdeveloped sub-sample $\beta = -0.247$, $p < 0.05$), validating the robustness of the benchmark conclusion. Second, the heterogeneity effect is amplified. Inter-group difference tests reveal that the absolute coefficient values for underdeveloped regions are significantly larger than those for developed regions ($p < 0.05$), further supporting the inclusive nature of digital finance. Finally, the consistency of control variables is maintained. The significance levels of variables such as fixed asset investment bias and talent supply align closely with the benchmark model (p -value fluctuations < 0.1 standard deviation).

As shown in **Figure 7**, the mean of the simulated coefficients is close to zero (0.003), and the standard deviation (0.042) is far smaller than the absolute value of the true coefficient (-0.127). This indicates that the benchmark results are not attributable to random noise. Furthermore, the statistics are statistically significant, with the true coefficient located at the extreme left end of the simulated distribution (0.6% percentile). with a

one-tailed p-value of $0.008 < 0.01$, leading to the rejection of the null hypothesis that "digital finance has no effect." Finally, the distribution exhibits symmetry, with simulated coefficients spanning the 5%–95% quantile range of $[-0.075, 0.082]$, validating the absence of systematic bias in the estimation method.

This study focuses on examining the macro-level moderating role of digital finance in regional development disparities. Leveraging its low-cost, wide-coverage, and sustainable characteristics, digital technology significantly enhances financial service inclusivity, offering an innovative pathway to mitigate regional imbalances. Empirical analysis validates the mechanism through which digital finance narrows regional gaps, with key findings including: (1) Digital finance development exhibits significant regional equalizing effects, particularly pronounced in stabilizing economically underdeveloped regions; (2) Optimized financing environments constitute a key transmission channel. The mediation model reveals that digital finance reduces regional disparities by improving financing accessibility through lowering market concentration in the banking sector. (3) The innovative vitality of enterprises, entrepreneurial activity among residents, and industrial structure upgrading exert moderating effects, synergistically enhancing the balancing effect of digital finance. Robustness tests employing variable substitution, placebo tests, and instrumental variables further validate the study's conclusions^[4].

3. Outlook and future

Deepening Mechanism and Spatial Spillover Identification: Building upon existing mediation/moderation analyses, we further incorporate spatial econometric frameworks (geographic adjacency, economic distance, or transportation accessibility weights) to identify the diffusion and spillover effects of digital finance across regions. **Microdata Integration and Causal Strengthening:** Match city-level panel data with firm/individual-level data, employing quasi-natural experiments, event studies, or difference-in-differences designs. Combine these with stronger instrumental variables and grouping strategies to enhance causal interpretability. **Indexing and Measurement Tooling:** Explore dynamic factor or Bayesian hierarchical models beyond PCA/TOPSIS, releasing reusable index calculation and visualization toolkits to improve intertemporal and interregional comparability. **Regional Differentiated Policy Simulation:** Construct policy scenarios integrating "digital financial inclusion enhancement × financing environment optimization × entrepreneurial innovation dynamism," evaluate dynamic impacts on cities across development gradients, and propose infrastructure-financial supply combinations tailored for underdeveloped regions. **Digital Divide and Inclusive Governance:** Assess the accessibility and usage depth of inclusive finance among vulnerable groups by integrating constraints such as demographic structure and income distribution. Refine risk prevention and consumer protection arrangements to ensure the sustainability and fairness of balanced outcomes.

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