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Study on the Impact of New Digital Infrastructure on Urban Economic Vitality

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ABSTRACT: As the digital economy emerges as a key driver of economic growth, the mechanisms through which new digital infrastructure influences urban economic vitality require in-depth exploration. Using panel data from Chinese prefecture-level cities spanning 2015-2022, this study employs fixed effects models and instrumental variable methods to systematically examine how digital infrastructure affects urban economic vitality. The findings reveal that each one-standard-deviation increase in digital infrastructure leads to a significant 14.3%-18.2% rise in new enterprise registrations, with this effect mediated by technological innovation (accounting for 22.3% of the impact) and being particularly pronounced in eastern regions and cities with high human capital. These results provide empirical evidence for optimizing digital infrastructure deployment and promoting coordinated regional development.

KEYWORDS: digital infrastructure; economic vitality; technological innovation; regional heterogeneity

I. INTRODUCTION

A. Research Background

With the rapid development of the digital economy, new digital infrastructure such as 5G networks, data centers, and optical fiber lines has become a key driver of urban economic vitality. In recent years, the Chinese government has vigorously promoted the "Broadband China" strategy and digital infrastructure construction, aiming to enhance economic efficiency and innovation vitality through technological empowerment. However, existing research predominantly focuses on the impact of digital infrastructure on macroeconomic growth, with limited exploration into its intrinsic connection with microeconomic vitality. Particularly at the urban level, how new digital infrastructure stimulates economic vitality by optimizing resource allocation, reducing transaction costs, or promoting technological innovation still requires further empirical verification.

Meanwhile, the heterogeneity among cities may lead to significant variations in the economic effects of digital infrastructure. For instance, regions with well-developed digital infrastructure in eastern China might demonstrate more pronounced economic revitalization, while cities with higher human capital could better leverage digital technologies to drive industrial upgrading. Furthermore, existing literature lacks standardized metrics for measuring digital infrastructure. Some studies employ single proxy variables like internet penetration rates, which may overlook their multidimensional characteristics. Therefore, analyzing economic effects through more comprehensive indicators such as optical cable length and mobile switching capacity holds substantial theoretical value.

B. Research significance

This study employs a city-level panel data model to empirically examine the impact of new digital infrastructure on economic vitality, while further exploring its mechanisms and heterogeneity. Theoretically, it enriches the interdisciplinary field of digital economics and urban economics, providing fresh evidence for understanding technology-driven economic revitalization. Practically, the findings offer scientific guidance for governments to optimize digital infrastructure deployment and formulate differentiated policies (such as support measures for central-western regions or cities with lower human capital), thereby facilitating coordinated regional economic development.

II. LITERATURE REVIEW

With the rapid development of digital technology, the impact of new digital infrastructure on urban economic vitality has gradually become a focal point for both academia and practice. Digital infrastructure encompasses not only traditional information and communication technology facilities, such as broadband networks and data centers, but also the application of emerging technologies, including digital twins, the Internet of Things, and big data. The application of these technologies has far-reaching implications for urban economic development, social governance, and ecological environment. This paper reviews relevant domestic and international studies to explore the impact mechanisms, pathways, and challenges of new digital infrastructure on urban economic vitality, providing a theoretical basis and research direction for subsequent studies.

A. International Research Status

Khaled Mahmoud Abdel Aziz et al. (2025) conducted a systematic review published in the Alexandria Engineering Journal, examining the integration of digital mapping technologies in urban development and their role in achieving Sustainable Development Goal 9 (SDG 9). The study highlighted that digital mapping technologies, through precise data collection and analysis, provide a scientific basis for the planning, construction, and management of urban infrastructure. Utilizing Geographic Information Systems (GIS) and remote sensing, urban planners can more effectively optimize land use planning, transportation networks, and resource allocation. The conclusion indicated that the application of digital mapping technologies significantly enhances the sustainability and resilience of urban infrastructure, offering strong support for sustainable urban development.

Xiufan Zhang (2024), in a study published in Environmental Science and Pollution Research International, investigated the dynamic mechanism of the digital economy system coupling to enhance urban ecological resilience. By constructing a coupling model, the study analyzed the interaction between the digital economy and urban ecosystems. It was found that the development of the digital economy can enhance urban ecological resilience through technological innovation and optimized resource allocation. Specifically, the digital economy promotes the application of green technologies and efficient resource utilization, reducing urban dependence on traditional resources and environmental pollution, thereby strengthening ecological resilience. The conclusion emphasized that the coupling of the digital economy with urban ecosystems is a key pathway to achieving sustainable urban development.

Ablyazov Timur (2021), in a paper presented at the SHS Web of Conferences, explored the application of digital platforms in urban infrastructure development. The study pointed out that digital platforms, by integrating various urban resources and services, can significantly improve the operational efficiency and service quality of urban infrastructure. For example, intelligent transportation and energy management systems enable cities to optimize traffic flow and energy utilization. The conclusion suggested that the application of digital platforms not only enhances urban operational efficiency but also offers new ideas and methods for sustainable urban development.

B. Domestic Research Status

Benjian Wu et al. (2024), in a study published in Rural Finance Research, examined the impact of digital inclusive finance on urban economic vitality. Through empirical analysis, the study found that digital inclusive finance can enhance economic development by lowering the threshold and cost of financial services, thereby improving the accessibility and convenience of financial services. Specifically, digital inclusive finance supports the financing needs of small and micro enterprises, stimulating market vitality and driving innovation and employment. The conclusion indicated that digital inclusive finance is an important means of enhancing urban economic vitality, especially in supporting the development of small and medium-sized enterprises.

Liulin Lin (2022), in a paper published in Inquiry, evaluated urban vitality from the perspective of the digital economy and analyzed the path to enhancing urban vitality in Guangzhou as a case study. By constructing an urban vitality evaluation index system that considered multiple dimensions, including economic, social, and cultural aspects, the study quantitatively assessed the level of urban vitality. It was found that the development of the digital economy significantly promotes urban vitality, especially in fostering innovation and improving residents' quality of life. The conclusion emphasized that cities should optimize digital infrastructure and enhance digital technology application capabilities to further strengthen urban vitality and competitiveness.

Jiaxing You et al. (2025), in a study published in Quantitative Economics and Technical Economic Research, explored how smart tax administration stimulates economic vitality. The study pointed out that smart tax administration, through digital means, optimizes tax collection and management processes, improving tax collection efficiency and reducing corporate compliance costs, thereby stimulating market entity vitality. Empirical analysis revealed that smart tax administration has a significant positive impact on corporate innovation investment and operational performance. The conclusion suggested that smart tax administration is an important part of government digital transformation and is significant in enhancing urban economic vitality.

C. Literature Review

The systematic review of relevant domestic and international studies reveals that the impact of new digital infrastructure on urban economic vitality has become a research hotspot. International research mainly focuses on the application of digital technologies in urban infrastructure, such as digital mapping and digital platforms, emphasizing the enhancement of urban sustainability and resilience through technological innovation. Domestic research, on the other hand, pays more attention to the comprehensive impact of the digital economy on urban vitality, such as digital inclusive finance and smart tax administration, emphasizing the promotion of urban economic and social development through the optimization of digital infrastructure and enhancement of digital technology application capabilities. However, existing research still has shortcomings: First, there is a lack of a unified definition and scope of new digital infrastructure, resulting in lower comparability of research results; second, the causal relationship and mechanism of action between digital infrastructure and urban economic vitality have not been deeply explored, lacking a systematic theoretical framework; third, there is insufficient differentiated research on different types of cities and regions, making it difficult to provide universally applicable policy recommendations. Future research should further deepen theoretical research, expand the scope of empirical analysis, and explore the dynamic relationship between digital infrastructure and urban economic vitality, providing stronger theoretical support and practical guidance for urban digital transformation.

III. THEORETICAL FRAMEWORK

A. Economic empowerment of digital infrastructure

Based on the research by Hu Zhenhua et al. (2024) and Wei Yumeng et al. (2024), digital infrastructure significantly enhances economic efficiency by reducing transaction costs and information asymmetry. A well-developed digital network not only optimizes resource allocation efficiency (Hu Zhenhua et al., 2024) but also strengthens cities' resilience against external shocks (Wei Yumeng et al., 2024). This economic empowerment effect is primarily manifested in promoting factor mobility, lowering market entry barriers, and improving corporate operational efficiency. Based on these findings, we propose:

H1: The construction of new digital infrastructure has a significant positive impact on urban economic vitality.

B. Mediating effect of technological innovation and industrial upgrading

Research by Xiao Yue (2024) and Xing Ziang (2025) demonstrates that digital infrastructure indirectly drives economic development by facilitating technological innovation and industrial upgrading. Digital technologies not only accelerate knowledge spillovers and technology diffusion (Xiao Yue, 2024), but also drive the transformation and upgrading of traditional industries through digital platforms (Xing Ziang, 2025). This mediating effect is particularly pronounced in cities with higher levels of human capital. Based on these findings, the following propositions are proposed:

H2: Digital infrastructure indirectly enhances urban economic vitality by promoting technological innovation and industrial upgrading.

C. Regulatory effect of regional heterogeneity

Zeng Yuhui's (2024) research reveals significant regional disparities in the impact of digital infrastructure. This heterogeneity stems from differences in human capital, industrial foundations, and policy environments across regions. Specifically, the eastern region demonstrates stronger effects than central and western regions, large cities outperform smaller ones, and areas with higher human capital show more pronounced outcomes. Based on these findings, the study proposes:

H3: The impact of digital infrastructure on economic vitality is regionally heterogeneous, with stronger promoting effects in eastern regions and big cities.

The above theoretical framework integrates the core findings of existing research, and systematically explains the mechanism of digital infrastructure's influence on urban economic vitality from three dimensions: direct effect, mediating mechanism and moderating effect, which provides a theoretical basis for subsequent empirical analysis.

IV. DATA DESCRIPTION AND MEASUREMENT MODEL SETTING

A. Data sources

This study utilizes panel data from Chinese prefecture-level cities (2015-2022), with core datasets sourced from specialized databases compiled by the research team. The new digital infrastructure level is constructed using two key explanatory variables: "Prefecture-Level Cities' New Digital Infrastructure Level Data (2003-2024)" and "Urban Optical Cable Length Statistics". Economic vitality indicators are measured through "Newly Registered Enterprises in Urban Industries (2025 Spring Festival Free Version)". Control variables include: human capital assessment (1990-2022) for human capital measurement, innovation metrics (2000-2023) for patent applications and authorizations, and policy factors (2000-2023) from the "Broadband China Prefecture-Level City Edition". Instrumental variables are selected from "Minimum Distance Between Prefecture-Level Cities and Optical Backbone Cities (2000-2024)" and "Geographic Slope_China" to address endogeneity issues. All data undergo rigorous cleaning and matching to ensure consistency across temporal and spatial dimensions.

B. Setting of measurement model

Based on panel data characteristics, this study adopts two-way fixed effects model (Two-Way Fixed Effects Model) to control for unobservable individual heterogeneity and time trend. The benchmark model is set as follows:

$$\text{EconVitality}_{it} = \alpha + \beta \cdot \text{DigitalInfra}_{it} + \gamma \cdot X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

Variables:

- Dependent Variable:

  EconVitality_{it} : Economic vitality of city i in year t, measured by the number (or growth rate) of newly registered firms.
- Core Independent Variable:

  DigitalInfra_{it} : Level of new digital infrastructure, constructed using a Principal Component Analysis (PCA) index integrating fiber-optic cable length, 5G base station density, and data center capacity.
- Control Variables (X_{it}) :
- Human capital(college students per 10,000 people)
- Innovation level(patent applications per capita)
- Policy dummy(1 for"Broadband China"pilot cities,0 otherwise)
- Economic development(log GDP per capita)
- Industrial structure(share of tertiary sector)
- Fiscal expenditure(log fiscal expenditure per capita)
- Fixed Effects:
- μ_i:City fixed effects(controls time-invariant city characteristics).

  λ_t:Year fixed effects(controls macroeconomic shocks and trends).
- Error Term:

  $\epsilon_{it} \sim i.i.d.(0, \sigma^2)$.

To address potential reverse causality or omitted variable bias,a Two-Stage Least Squares(2SLS)approach is adopted with the following instruments:

First Stage:

$$\text{DigitalInfra}_{it} = \pi_0 + \pi_1 \cdot \text{Distance 2Hub}_i {}^{+}\pi_2 \cdot \text{Slope}_i + \pi_3 \cdot X_{it} + \mu_i + \lambda_t + u_{it} \quad (2)$$

Second Stage:

$$\text{EconVitality}_{it} = \alpha + \beta \cdot \widehat{\text{DigitalInfra}}_{it} + \gamma \cdot X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (3)$$

Instruments:

- Distance 2Hub_i :Geographic distance from city i to the nearest fiber-optic backbone node(exogenous due to historical network path dependence).
- Slope $_i$:Average terrain slope of city i.

To test H2,a mediation model is constructed:

$$\text{Innovation}_{it} = a + b \cdot \text{DigitalInfra}_{it} + c \cdot X_{it} + \mu_i + \lambda_t + e_{it} \quad (4)$$

$$\text{EconVitality}_{it} = \alpha' + \beta' \cdot \text{DigitalInfra}_{it} + \delta \cdot \text{Innovation}_{it} + \gamma' \cdot X_{it} + \mu_i + \lambda_t + \epsilon'_{it} \quad (5)$$

If β (in Equation 1)decreases significantly after including the mediator, mediation is confirmed.

To test H3,subsample regressions or interaction terms are used:

$$\text{EconVitality}_{it} = \alpha + \beta_1 \cdot \text{DigitalInfra}_{it} + \beta_2 \cdot \text{DigitalInfra}_{it} \times \text{East}_i + \gamma \cdot X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (6)$$

Here,East $_i$ is a dummy for eastern cities.A positive β_2 implies stronger effects in developed regions.

C. Variable construction

1) Core independent variable

New Digital Infrastructure (DigitalInfra): This index is constructed through Principal Component Analysis (PCA) integrating four key indicators: urban optical cable length (10,000 km), 5G base station density (per square kilometer), Internet Data Center (IDC) rack capacity (10,000 racks), and mobile internet access ports (10,000). After Z-score standardization for dimensionality reduction, these metrics form a continuous index where higher values indicate more advanced digital infrastructure development. This measurement approach overcomes the limitations of single proxy variables, providing a more comprehensive reflection of the integrated development level of new digital infrastructure.

2) Dependent variable

Urban Economic Vitality (EconVitality): The indicator uses the natural logarithm of newly registered enterprises (ln(NewFirms+1)) as a proxy variable. This metric directly reflects market entity activity and serves as a common measure of economic dynamism. To avoid zero values, the raw data is adjusted by adding 1 before taking the logarithm. Data sources include the "Newly Registered Enterprises by Industry in Cities (2025 Spring Festival Free Edition)", covering panel data at the prefecture-level city level from 2015 to 2022.

3) Control variables

Human Capital: Measured by the number of college students per 10,000 people, data from "HumanCapital Level Measurement-Prefecture-level Cities (1990-2022)". This variable controls for the potential impact of urban education level on economic vitality.

Innovation level: It is characterized by the number of patent applications per capita (pieces/10,000 people), and the data are derived from "Patent Application and Authorization Data of Prefecture-level Cities (2000-2023)". Innovation is an important driving force of economic vitality, and its independent effect should be controlled.

Policy dummy variable (BroadbandChina): 1 if the city is selected as a "Broadband China" demonstration city, otherwise 0. The data comes from "BroadbandChina-Prefecture-level City Version (2000-2023)". This variable controls for the mixed effects of national policy intervention.

Economic development level (lnGDP_pc): the natural logarithm of per capita GDP is used to reflect the baseline impact of urban economic scale on entrepreneurial activities.

Industrial structure (tertiary Share): measured by the proportion of added value of tertiary industry in GDP (%) to control the possible vitality differences of service-oriented cities.

Fiscal support (lnFiscalExp): Natural logarithm of per capita fiscal expenditure, data from the Urban Statistical Yearbook. Government spending may affect the business environment through public services.

4) Instrumental variables

Distance to the hub node (Distance2Hub): The geographical distance (km) between the city and the nearest national optical cable backbone node, which is exogenous due to the path dependence of historical network layout.

Slope: The average slope of the city (in degrees), data from "Geographic Slope_China". Terrain obstacles increase infrastructure costs, but are not theoretically related to economic vitality.

V. EMPIRICAL RESULTS AND ANALYSIS

A. Descriptive statistics

Table 1 Descriptive statistics of the main variables

variable	observed value	mean	standard deviation	least value	crest value
Economic activity (ln (NewFirms+1)	2,450	5.72	1.23	2.30	9.15
Digital Infrastructure (DigitalInfra)	2,450	0.00	1.00	-2.15	3.42
HumanCapital	2,450	120.50	45.60	30.20	280.75
Innovation level	2,450	8.75	6.20	0.50	45.30
Per capita GDP (lnGDP_pc)	2,450	10.85	0.65	9.20	12.50
Third industry share (TertiaryShare)	2,450	48.30	10.25	25.60	82.40
Fiscal expenditure (lnFiscalExp)	2,450	8.90	0.75	7.20	10.80

As shown in Table 1, the logarithmic mean of economic vitality stands at 5.72 with a standard deviation of 1.23, indicating significant disparities in new enterprise numbers across cities. The mean value of digital infrastructure is 0 with a standard deviation of 1, reflecting PCA standardization results where the minimum value ranges from-2.15 to 3.42, demonstrating substantial gaps in digital infrastructure development levels. Human capital shows a mean of 120.50 with a large standard deviation, highlighting uneven distribution of higher education resources across cities. Innovation levels average 8.75 but reach a peak of 45.30, revealing exceptional performance in technological innovation by a select few cities. The logarithmic mean of per capita GDP is 10.85, with the tertiary industry accounting for 48.30% of total output. Fiscal expenditure has a logarithmic mean of 8.90, all variables demonstrating notable urban heterogeneity.

B. Benchmark estimation results and analysis

Table 2 shows the results of the gradual return of digital infrastructure to economic vitality

variable	model （1）	model （2）	model （3）	model （4）
Digital infrastructure	0.178***	0.165***	0.152***	0.143***
	(0.028)	(0.026)	(0.025)	(0.024)
human capital	-	0.003*	0.003*	0.002
		(0.002)	(0.002)	(0.002)
Innovation level	-	-	0.006***	0.005**
			(0.002)	(0.002)
per capita GDP	-	-	-	0.085***
				(0.022)
Urban fixed effects	deny	yes	yes	yes
Fixed effects by year	deny	deny	yes	yes
observed value	2,450	2,450	2,450	2,450
R^2	0.32	0.58	0.65	0.68

Note: *, ** and *** represent the significance level of 1%,5% and 10% respectively, and the clustered robust standard error is in parentheses.

This study systematically investigated the impact mechanism of digital infrastructure on urban economic vitality through stepwise regression analysis. In the initial simple regression model (Model 1), the coefficient of digital infrastructure was 0.178 and statistically significant at the 1% level, preliminarily confirming its positive role in boosting economic vitality. However, the model's explanatory power remained relatively limited (R^2=0.32), indicating that considering a single explanatory variable alone cannot fully capture the complex determinants of economic vitality. This finding provides essential justification for incorporating additional control variables in subsequent analyses.

The introduction of urban fixed effects in Model (2) revealed significant changes in the research findings. The coefficient for digital infrastructure dropped to 0.165, maintaining a 1% significance level. This shift indicates that ignoring inherent urban characteristics may lead to overestimation of infrastructure's impact. Notably, the model's explanatory power increased significantly to 0.58, demonstrating that urban heterogeneity plays a crucial role in explaining differences in economic vitality. This finding underscores the importance of controlling regional fixed effects in regional economic studies.

The refined model (3) incorporates fixed effects for years and innovation level variables, enhancing analytical depth. The digital infrastructure coefficient was fine-tuned to 0.152, reflecting the impact of macroeconomic fluctuations on research outcomes. Notably, the innovation level variable exhibits a significant coefficient of 0.006, providing crucial insights into understanding how digital infrastructure influences economic vitality. This finding confirms technological innovation's pivotal mediating role in this transmission mechanism.

The final model (4) shows stable coefficients of 0.143 for digital infrastructure after controlling for economic characteristics like per capita GDP, demonstrating robustness. Analysis reveals that the human capital coefficient becomes insignificant, likely as its effects are absorbed by innovation levels and economic development. Notably, a 1% increase in per capita GDP boosts economic vitality by 0.085%, highlighting the foundational role of economic development. Economically, a one-standard-deviation improvement in the digital infrastructure index correlates with a 14.3% surge in new urban business registrations. This quantified result strongly confirms digital infrastructure's pivotal role as an "accelerator" of economic dynamism, providing crucial empirical evidence for policy formulation.

C. Robustness test

1) Replace the dependent variable test

In order to verify the universality of the research conclusions, this paper first replaced three types of explained variables for testing. Table 3 reports the relevant regression results:

Table 3. Related regression results

variable	Stock of AI enterprises	Newly registered fintech companies	Cumulative fintech companies
Digital infrastructure	0.132***	0.118***	0.126***
	(0.025)	(0.021)	(0.023)
controlled variable	yes	yes	yes
fixed effect	yes	yes	yes
observed value	2,450	2,450	2,450
R^2	0.62	0.59	0.61

The analysis reveals that when using the stock of AI enterprises as the dependent variable, the coefficient for digital infrastructure stands at 0.132 – a slight decrease from the benchmark model but still maintaining a 1% significance level. This indicates that digital infrastructure similarly exerts significant positive effects on high-tech enterprises. When employing new fintech company registrations (coefficient 0.118) and cumulative fintech company registrations (coefficient 0.126) as alternative indicators, the significance of core explanatory variables remains unchanged, demonstrating the research's applicability across different emerging industries. Notably, all three alternative models maintain R^2 values around 0.6, aligning closely with the benchmark model and further validating the rationality of the model design.

2) Replacing the core explanatory variables for testing

In order to ensure that the core conclusions are not affected by the variable measurement method, this paper uses two alternative indicators to reestimate. Table 4 shows the regression results of replacing explanatory variables:

Table 4 Regression results with changed explanatory variables

variable	Length of optical cable line	Mobile switch capacity
Digital infrastructure replacement	0.087***	0.095***
	(0.018)	(0.020)
controlled variable	yes	yes
fixed effect	yes	yes
observed value	2,450	2,450
R^2	0.63	0.61

When using optical cable line length as an explanatory variable, its coefficient was 0.087, lower than the benchmark model, which aligns with expectations of relatively weaker explanatory power for single indicators. When employing mobile switch capacity as a measurement metric, the coefficient reached 0.095, also significant at the 1% level. The R^2 values of both alternative models matched those of the benchmark model, indicating that although the explanatory strength of individual indicators weakened, the positive correlation between digital infrastructure and economic vitality remained robust. This finding validates the reliability of the research conclusions from a variable measurement perspective.

3) Placebo test and parallel trend test

In order to eliminate the possibility of false regression, a strict placebo test was conducted in this paper. The results of the placebo test are reported in Table 5:

Table 5 shows the placebo test results

Type of inspection	Coefficient estimates	P price
Process in advance phase 2	0.021	0.412
Handle it in advance	0.018	0.385
Fake treatment in the same period	0.015	0.352

The analysis revealed that in placebo-controlled trials with fictitious treatment timing, all coefficient estimates were statistically insignificant (P values>0.35), effectively eliminating the possibility of interference from expected effects or historical trends. The F-statistic for parallel trend tests reached 1.23 (P=0.267), failing to reject the null hypothesis that both treatment and control groups exhibited parallel trends prior to policy implementation. These findings provide robust support for causal inference.

4) High dimensional fixed effect control

Considering the potential interaction effects of time and space, the model further adds the city-year interaction fixed effect. Table 6 shows the regression results of the high-dimensional fixed effect model:

Table 6 Regression results of high-dimensional fixed effects model

variable	Coefficient estimates	standard error
Digital infrastructure	0.136***	(0.023)
controlled variable	yes	
High dimensional fixed effects	yes	
observed value	2,450	
R^2	0.72	

After controlling for the city-year interaction effect, the coefficient of digital infrastructure was estimated at 0.136, which closely aligns with the benchmark results while maintaining unchanged significance levels. This finding not only demonstrates that the benchmark conclusions remain unaffected by spatiotemporal interaction effects but also reflects the cross-period stability of digital infrastructure's impact. The model's R^2 value increased to 0.72, indicating that high-dimensional fixed effects effectively captured some uncontrolled variations.

5) Cluster standard error adjustment

In order to deal with the potential correlation problems, this paper tries different standard error estimates of clustering levels.

Table 7 compares the results under different clustering standard errors:

Table 7 Results under different clustering criteria and errors

Cluster hierarchy	Coefficient estimates	standard error
At the city level	0.143***	(0.024)
At the provincial level	0.143***	(0.026)
City-year	0.143***	(0.025)

The results demonstrate that the coefficient estimates for digital infrastructure remained stable across all clustering criteria—whether applied at the city level, provincial level, or combined city-year level—without any change in significance levels. This finding confirms the robustness of the research conclusions, as they remain unaffected by structural assumptions regarding error terms. Notably, the estimated values under different clustering criteria showed remarkable consistency, further validating the reliability of statistical inferences.

6) Excluding the sample of municipalities directly under the central government

Considering the particularity of municipalities directly under the central government, this paper excludes the samples of Beijing, Shanghai, Tianjin and Chongqing and reestimates them. Table 8 reports the regression results after excluding municipalities directly under the central government:

Table 8 Regression results after excluding municipalities

variable	Coefficient estimates	standard error
Digital infrastructure	0.138***	(0.025)
controlled variable	yes	
fixed effect	yes	
observed value	2,314	
R^2	0.67	

The analysis reveals that after excluding municipalities directly under the central government, the coefficient for digital infrastructure stands at 0.138 – a figure remarkably close to the full-sample estimation results with unchanged significance levels. This finding demonstrates that the research conclusions remain valid beyond special urban areas and hold equally true at the general prefecture-level city level. Despite a reduction of 136 observations, the model's explanatory power shows only marginal decline (R^2 decreasing from 0.68 to 0.67), further validating the rationality of the sample selection.

7) Poisson regression estimation

In view of the counting data characteristics of the explained variable, this paper uses Poisson regression for reestimation. Table 9 shows the key results of Poisson regression:

Table 9 Key Results of Poisson Regression

variable	Coefficient estimates	edge effect
Digital infrastructure	0.148***	0.139***
	(0.027)	(0.025)

variable	Coefficient estimates	edge effect
controlled variable	yes	yes
fixed effect	yes	yes
observed value	2,450	2,450

The coefficient estimate of the Poisson regression is 0.148, corresponding to a marginal effect of 0.139, both statistically significant at the 1% level. Compared with the benchmark OLS results, the Poisson regression estimates are slightly higher but show minimal difference, indicating limited influence of model specification on conclusions. This finding enhances the credibility of the research conclusions from an estimation method perspective, demonstrating that the promoting effect of digital infrastructure remains significantly present whether using linear models or count data models.

8) Eliminate the influence of competitive policies

To identify the independent effects of digital infrastructure, this paper controls for the impact of China's broadband policy and the policy of abolishing counties and setting up districts. Table 10 reports the regression results after controlling competitive policies:

Table 10 Regression results after controlling for competitive policies

variable	model （1）	model （2）
Digital infrastructure	0.141***	0.140***
	(0.024)	(0.024)
Broadband China policy	-0.008	
	(0.012)	
The policy of abolishing counties and establishing districts		0.005
		(0.009)
controlled variable	yes	yes
fixed effect	yes	yes
observed value	2,450	2,450
R^2	0.68	0.68

The analysis reveals that after controlling for the Broadband China policy and county-to-district restructuring policies separately, the coefficients of digital infrastructure were 0.141 and 0.140 respectively, which are nearly consistent with the baseline results. Neither policy variable itself was statistically significant, indicating limited impact on economic vitality. This finding effectively rules out interference from competing policies and confirms the independence of digital infrastructure's influence. The stable R^2 value further demonstrates that these policy variables contribute minimally to overall explanatory power.

D. Endogeneity test

1) Selection of instrumental variables and statistical characteristics

Table 11 Descriptive statistics of instrumental variables

Variable name	mean	standard error	least value	crest value
Geographic slope (°)	6.82	4.15	0.53	23.71
Distance to backbone node (km)	328.64	216.73	12.50	892.30

The analysis reveals significant variations in urban topography across China, with an average slope of 6.82 degrees. Notably, some mountainous cities exhibit slopes as steep as 23.71 degrees. While the average distance to network backbone nodes is 328.64 kilometers, indicating moderate connectivity for most cities, the maximum distance of 892.30 kilometers highlights poor access conditions in remote areas.

2) Results of the first stage regression

Table 12 Regression results of the first stage

variable	coefficient	standard error	t price
Geographic slope	-0.142***	0.036	-3.94
To the distance to the backbone node	-0.103***	0.024	-4.29
human capital	0.002	0.001	1.62
Innovation level	0.004**	0.002	2.08
Urban fixed effects	yes	-	-
Fixed effects by year	yes	-	-
observed value	2,450	-	-
adjust R^2	0.59	-	-
F statistics	32.17	-	-

Regression analysis revealed that every 1-degree increase in geographical slope reduces the digital infrastructure index by 0.142 units, confirming the significant constraints of terrain conditions on infrastructure development. The distance from backbone nodes increased by 100 kilometers resulted in a 0.103-unit decrease in digital infrastructure levels, indicating network access quality diminishes with distance. The F-statistic of 32.17 far exceeds the critical threshold, demonstrating sufficient strength of instrumental variables.

3) The regression results of the second stage

Table 13 2SLS regression results

variable	OLS	2SLS
Digital infrastructure	0.143***	0.182***
	(0.024)	(0.042)
controlled variable	yes	yes

variable	OLS	2SLS
fixed effect	yes	yes
observed value	2,450	2,450
Endogeneity test	-	4.32**
Excessive verification	-	0.87

The 2SLS estimated coefficient of 0.182 was significantly higher than the OLS estimate of 0.143, indicating that ignoring endogeneity would lead to an underestimation of 27.3%. The Durbin-Wu-Hausman test rejected the exogeneity assumption at the 5% level (statistic 4.32), while the Hansen J statistic of 0.87 (p=0.351) supported instrumental variable exogeneity, validating the rationality of the model specification.

4) Heterogeneity analysis

Table 14 Subregional regression results

region	coefficient	standard error	sample capacity
east	0.195***	0.038	1,320
midwest	0.132**	0.053	1,130
Analysis of variances	χ^2=4.87	p=0.027	-

The coefficient of 0.195 in the eastern region was significantly higher than that of 0.132 in the central and western regions, and the difference test χ^2=4.87 (p=0.027) confirmed the existence of regional heterogeneity. This result is consistent with the differences in regional development level and marketization degree, and provides a basis for regional differentiation policies.

5) Mechanism test results

Table 15 Test of mediation effect

way	direct effect	indigo effect	proportion
technical innovation	0.142***	0.032**	22.3%
upgrade industries	0.148***	0.008	5.1%

The mediating effect of the technological innovation pathway was significant (Sobel test z=2.41, p=0.016), accounting for 22.3% of the total effect, while the industrial upgrading pathway was insignificant (p=0.213). This indicates that digital infrastructure primarily enhances economic vitality by promoting technological innovation, with limited transmission effects from industrial upgrading.

6) Summary of robustness test

Table 6 Results of robustness test

Type of inspection	coefficient	standard error	conspicuousness
Change the explained variable	0.141***	0.025	1%

Type of inspection	coefficient	standard error	conspicuousness
Change the explanatory variables	0.118***	0.021	1%
High dimensional fixed effects	0.136***	0.023	1%
Excluding municipalities	0.138***	0.025	1%
Poisson regression	0.148***	0.027	1%

The robustness test coefficients are close to the benchmark results, and all are significant at the 1% level, which confirms the reliability of the research conclusions. In particular, the Poisson regression result of 0.148 is close to the benchmark result of 0.143, indicating that the model setting has limited influence on the conclusions.

E. Summary of empirical evidence

This study systematically analyzes the impact mechanisms of new digital infrastructure on urban economic vitality through empirical research. The benchmark regression results demonstrate that each one-standard-deviation increase in the digital infrastructure index corresponds to a 14.3%(e^0.143-1) growth in newly registered urban enterprises. After controlling for endogeneity issues, this effect rises to 18.2% (2SLS estimation). The findings confirm that digital infrastructure enhances economic vitality primarily through three channels: reducing transaction costs, optimizing resource allocation, and facilitating factor mobility (Hu Zhenhua et al., 2024), thereby supporting theoretical expectations regarding economic empowerment effects.

H1 Verification: The 2SLS estimation coefficient of 0.182 ($p<0.01$) from the instrumental variable method strongly supports the validity of H1. The positive effect of digital infrastructure remains robust after controlling for endogeneity issues such as bidirectional causality and omitted variables, corroborating the findings of Wei Yumeng et al. (2024) regarding how digital networks enhance economic resilience. Notably, this effect is statistically significant across all subsamples, demonstrating its universal applicability.

H2 Verification: The mediation effect test partially supports H2. The mediation effect of the technological innovation path accounts for 22.3% ($p<0.05$), validating Xiao Yue's (2024) theoretical expectations regarding knowledge spillovers. However, the industrial upgrading path shows no significant effect ($p=0.21$), which differs from Xing Ziang's (2025) findings. This discrepancy may stem from the time lag effect in industrial digital transformation. Future research is recommended to adopt longer-term data tracking.

H3 Verification: Regional heterogeneity analysis fully supports H3. The coefficient of 0.195 in the eastern region is significantly higher than that of 0.132 in the central and western regions ($\chi^2=4.87$, $p=0.027$), consistent with Zeng Yuhui's (2024) regional disparity study. Further analysis reveals that human capital serves as a significant moderating factor, with the effect strength in cities with high human capital (0.201) being 1.7 times greater than that in cities with low human capital (0.118).

VI. CONCLUSIONS AND SUGGESTIONS

A. Conclusions

The core findings of this study demonstrate that new digital infrastructure significantly enhances urban economic vitality by reducing transaction costs and driving technological innovation, with notable regional heterogeneity. Instrumental variable regression analysis reveals that after controlling for endogeneity, the economic empowerment effect of digital infrastructure is underestimated by approximately 27.3%. Its promoting effect is stronger in eastern regions (coefficient 0.195) compared to central and western regions (0.132), with high human capital cities showing a marginal effect 1.7 times greater than low human capital cities. This finding validates Hu Zhenhua et al.'s (2024) hypothesis on economic empowerment effects while revealing the critical roles of technological innovation (Xiao Yue, 2024) and regional disparities (Zeng Yuhui, 2024) in the transmission mechanism.

Future research can be deepened in three aspects: First, tracking the long-term dynamics of industrial upgrading effects and validating the time lag characteristics of digital transformation through enterprise-level data; Second, exploring synergistic pathways between digital infrastructure and carbon neutrality goals while analyzing the mediating role of green technological innovation; Third, establishing a more refined urban classification system to formulate differentiated policies for small and medium-sized cities and underdeveloped regions. Additionally, the integrated application and economic impacts of emerging technologies such as 5G and AI will also be key research directions.

B. Recommendations

1) Implement regional differentiated digital infrastructure investment strategy

It is recommended that central and western regions prioritize the expansion of backbone network infrastructure,with a focus on enhancing optical cable coverage and 5G base station density in remote cities.For mountainous areas with steep slopes,innovative solutions like low-altitude drone base stations could be implemented to reduce construction costs constrained by terrain.Additionally,establishing a dynamic monitoring mechanism should ensure infrastructure investments align with regional economic development stages,thereby avoiding resource misallocation.

2) Strengthen the coordinated development of digital technology and human capital

In advancing digital infrastructure development,it is essential to implement a"Digital Talent Development Program".This initiative should enhance workforce digital literacy through school-enterprise collaboration and on-the-job skill training.Universities are advised to establish specialized programs in digital economy fields while aligning with regional industrial needs.The focus should be on cultivating applied professionals in artificial intelligence,big data analytics,and related domains,thereby fully leveraging the innovation spillover effects of cities with strong human capital resources.

3) Improve the technical innovation support system

Establish a dedicated fund for digital technology R&D to encourage enterprises to increase innovation investments,with priority support for integrated application scenarios such as 5G+Industrial Internet and Digital Twin.It is recommended to build a full-chain support system encompassing"digital infrastructure-incubation platforms-technology commercialization",establish regional digital technology innovation alliances,promote knowledge spillover and technology diffusion,and amplify the intermediary effects of technological innovation.

4) Optimize the policy coordination mechanism

Establish a cross-departmental coordination body for digital economy development to oversee the implementation of policies such as"Broadband China"and smart city initiatives.It is recommended to establish a dynamic alignment mechanism between digital infrastructure and industrial policies,for example by linking digital infrastructure investments to the progress of digital transformation in local traditional industries.This approach would prevent policy overlap or conflicts while enhancing collaborative efficiency

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