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Asymmetric effects of internet penetration on high-quality financial development in a resource-depleted Chinese city: Evidence from Jiaozuo

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ABSTRACT

This study investigates the asymmetric effects of internet development on high-quality financial development in resource-exhausted cities, with Jiaozuo serving as a representative case. Jiaozuo is selected as a representative case due to its status as a typical resource-exhausted city undergoing institutional and economic transformation. It challenges the conventional assumption that digital expansion uniformly enhances financial performance in structurally constrained environments. Employing a Nonlinear Autoregressive Distributed Lag (NARDL) model on annual data from 2000 to 2023, the analysis decomposes internet penetration into positive and negative changes to examine their differential impacts on a composite index of financial development quality. R&D intensity, economic openness, income level, are incorporated as control variables. The results show that positive internet shocks do not have a statistically significant impact on high-quality financial development, while negative shocks, although causing short-term disturbances, are conducive to long-term institutional adaptation and systemic improvements. According to the results, policies should prioritize institutional capacity building and digital financial literacy over indiscriminate infrastructure expansion, consistent with the *Sustainable Development Plan for Resource-Exhausted Cities* from 2025-2027. Reforms in financial governance and sustained innovation support are essential to advance digital-financial integration, in alignment with the *14th Five-Year Plan for Digital Economy Development* for 2028-2035 targets.

Contribution/ Originality: This study contributes to the literature by examining the nonlinear, asymmetric effects of Internet penetration on high-quality financial development in a resource-depleted city using a NARDL framework. It offers new insights into the direction of shocks under path dependence, demonstrating that managed slowdowns catalyze institutional upgrading and lead to long-term gains in depth, inclusion, and resilience.

1. INTRODUCTION

Resource-depleted cities have become a persistent challenge for China's regional development. Once reliant on coal and other extractive industries, many now face slow growth, out-migration, and narrow industrial bases. Given their role in national industrialization, their transition bears directly on regional balance and sustainability (Ai & Kim, 2024; State Council of the People's Republic of China, 2007). Jiaozuo, Henan, exemplifies these dynamics. From the 1950s to the early 2000s, it depended on coal mining and metallurgy. In 2008, it was designated a resource-depleted city, marking a shift toward contraction and adjustment (State Council of the People's Republic of China, 2007). Since then, industrial scale and growth have weakened. GDP growth fell from 11.9% in 2010 to 5.4% in 2024, and performance has lagged the provincial average since 2014. The city also suffered a sharp -20.6% contraction in 2020,

far worse than Henan's 1.1% (Henan Provincial Bureau of Statistics, 2024) underscoring heightened vulnerability (Figure 1).

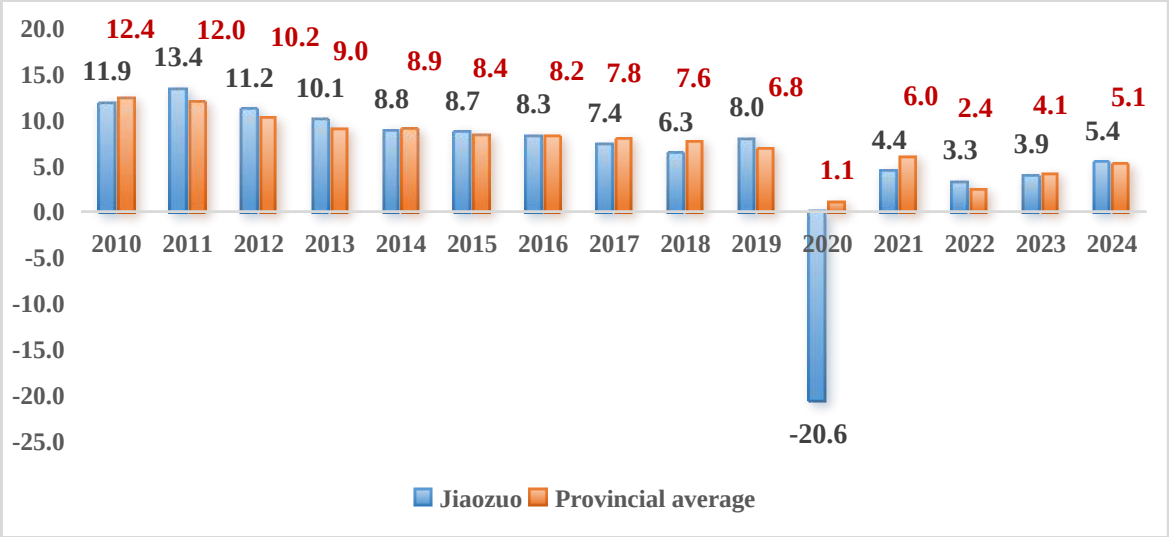

Figure 1. Jiaozuo and Provincial average GDP growth rate from 2010-2024(%).

Policymakers have increasingly turned to the digital economy to diversify and renew resource-depleted cities. National blueprints, including the National Sustainable Development Plan for Resource-Exhausted Cities (2013–2020) and the 14th Five-Year Plan for Digital Economy Development, prioritize digital infrastructure and internet-based industries (State Council of the People's Republic of China, 2013, 2021). The rationale is that e-commerce, digital finance, and AI-enabled manufacturing reduce frictions and rely less on physical networks, making them suitable for constrained regions (Ediagbonya & Tioluwani, 2023; Gruin & and Knaack, 2019).

Notwithstanding this policy orientation, observed impacts are heterogeneous across locales. National internet penetration increased by 24.3 percentage points from 2015 to 2022 (China Internet Network Information Center, 2023). Over the same period, resource-based cities recorded an average growth in the loan-to-deposit ratio that was about 1.8 times lower than in non-resource cities (State Council of the People's Republic of China, 2013). This divergence between expanding connectivity and limited financial deepening challenges the assumption of a linear relationship between the internet and finance and highlights mediating institutional constraints, motivating a non-linear and asymmetric assessment in this context.

Existing literature tends to assume a linear and positive relationship, yet such assumptions may not hold under conditions of institutional inertia, legacy industrial dominance, and limited financial literacy (Haini & Pang, 2022; Salahuddin & Gow, 2016). More importantly, the direction of Internet shocks, whether positive or negative, may produce asymmetric effects on financial outcomes, a dynamic often overlooked in prior research.

This paper addresses the gap by examining the nonlinear, asymmetric link between internet development and high-quality financial development in Jiaozuo, a resource-constrained city in digital transition. A nonlinear autoregressive distributed lag (NARDL) model identifies distinct effects of positive and negative changes in internet penetration under the institutional and economic constraints typical of inland cities. The study's novelty is operationalized along three dimensions. First, by separating the impacts of positive and negative digital shocks, it highlights divergent causal pathways that operate under distinct local conditions. Second, a city-level index of high-quality financial development, consistent with China's "new development" emphasis, is constructed using entropy weights across innovation, coordination, openness, and inclusion. Third, path dependence and asymmetric-shock mechanisms are integrated to interpret adjustment in resource-dependent settings and to derive sequenced policy design.

2. LITERATURE REVIEW

Although prior studies have linked digital infrastructure to financial sector development, few have examined how this relationship unfolds in cities whose economies remain tied to natural resources. This review consolidates three main areas of scholarly work to better understand the unique challenges and opportunities faced by Jiaozuo in developing internet finance amid its resource limitations.

The role of internet penetration as a catalyst for high-quality financial development has been extensively documented, emphasizing its capacity to enhance financial inclusion. An increasing number of studies have shown that digital infrastructure plays a crucial role in reducing transaction costs and expanding access to credit for individuals and businesses (Iwedi, 2024; Tian & Lu, 2023). It has also given rise to new forms of financial activity, including mobile payments and peer-to-peer lending (Gomber, Kauffman, Parker, & Weber, 2018). In China, platforms such as Alipay and WeChat Pay have fundamentally transformed the delivery of financial services to small and medium-sized enterprises (SMEs), particularly in economically developed urban areas. While these innovations have deepened financial markets in certain regions, their impact on structurally constrained or underdeveloped cities remains understudied. Nevertheless, this optimistic view presumes a uniformity in institutional and economic conditions that may not exist. In resource-depleted cities like Jiaozuo, structural challenges could impede the anticipated positive outcomes of internet-driven financial development.

While digital expansion holds substantial promise, cities suffering from resource depletion encounter distinctive challenges that may impede the advancement of their financial sectors. The concept of institutional path dependence, often discussed in "resource curse" literature (Fagbemi & Kotey, 2024), highlights issues such as regulatory inertia, where traditional banking frameworks prefer state-owned enterprises over SMEs that are native to the digital era (Vagliasindi, Cordella, & Clifton, 2022). Furthermore, deficits in human capital limit the integration of Fintech solutions. Disparities in spatial development further complicate matters, as advanced digital infrastructure, such as 5G networks, is predominantly located in urban centers, leaving rural financial institutions inadequately served (Ashfaq, 2024). These issues form a paradox where the expansion of internet capabilities surpasses the capacity for institutional adaptation, resulting in a "digital divide within digitization" that restrains rather than stimulates financial progress.

Recent research challenges the traditional view that internet development uniformly promotes financial growth in a linear fashion. Instead, nonlinear models suggest that the relationship between digitalization and financial systems is highly influenced by specific contextual factors, with effects that vary depending on certain thresholds and the nature of shocks. For example, internet penetration can only significantly improve financial development once it exceeds a critical threshold (Zhang, Li, Mao, & Wang, 2023). Noh and Yoo (2008) examined the relationship between Internet usage, income inequality, and financial growth. They found that in countries with high levels of income inequality, greater Internet usage may have a negative impact on the development and stability of the financial sector (Noh & Yoo, 2008). It appears that the benefits of digitalization may diminish due to structural limitations. At the same time, negative shocks could intensify financial vulnerabilities. This nonlinear understanding helps shed light on why resource-depleted cities tend to experience weaker financial gains from digital growth compared to more diversified economic regions.

Table 1 provides an overview of recent studies on how internet development affects high-quality financial development. While much of the literature points to its potential benefits, such as improving access and efficiency, other research emphasizes the challenges that may limit these effects, especially in resource-dependent cities like Jiaozuo.

Table 1. Summary of literature on internet development and high-quality financial development.

Impact type	Key findings	Representative studies
Positive	Internet development improves financial inclusion, lowers transaction costs, enhances SME credit access, and promotes innovation through platforms such as mobile payments and P2P lending.	Gomber et al. (2018) and Tian and Lu (2023)
Negative	Institutional inertia, human capital deficits, and spatial inequality hinder digital finance in resource-depleted cities. Financial systems remain biased toward SOEs; rural areas lack infrastructure.	Ashfaq (2024); Fagbemi and Kotey (2024) and Vagliasindi et al. (2022)
Nonlinear/ Threshold	Internet development benefits only emerge beyond a certain threshold. In unequal or underdeveloped regions, digitalization may even undermine financial stability.	Zhang et al. (2023)

Taken together, existing findings indicate that internet-finance effects are contingent on institutional capacity and the direction of shocks. This study addresses the neglected city-level asymmetries using a NARDL framework and an HQFD index operationalized along innovation, coordination, openness, and inclusion.

3. THEORETICAL FRAMEWORK AND METHODOLOGY

To dissect the nuanced relationship between internet development and high-quality financial development in resource-exhausted cities such as Jiaozuo, this study harnesses two complementary theoretical lenses: Path Dependence Theory and Asymmetric Shock Theory. These frameworks elucidate how institutional inertia, historical legacies, and the directional nature of shocks shape the evolution of financial systems in emerging digital contexts.

The study proposed the path dependence theory, which reveals a core proposition: the institutional trajectories formed by history will continue to shape the evolutionary direction of economic systems through self-reinforcing mechanisms in industrial structure, policy frameworks, and interest patterns (Dobusch & Kapeller, 2013). This theory is particularly applicable to explaining the digital transformation dilemma of resource-depleted cities. When the production organization methods, skill systems, and regulatory models of traditional energy economies form rigid structures, they often produce institutional lock-in effects that inhibit financial innovation. It is worth noting that economic systems exhibit significant asymmetry in their responses to exogenous shocks. As the McAleer, Hoti, and Chan (2009) found through empirical analysis, the driving efficacy of positive technological diffusion and negative market shocks on institutional change differs fundamentally (McAleer et al., 2009). In the unique context of resource-dependent economies, sudden negative shocks not only expose systemic vulnerabilities but may also reinforce the conservative tendencies of existing institutions through the 'trauma memory' effect (Laguarda, Hickel, Schrijer, & van Oudheusden, 2020). This unique shock response mechanism provides a new theoretical lens for understanding the barriers to the penetration of digital finance in traditional industrial cities.

In resource-scarce cities, the economic and social impacts of internet development often exhibit significant asymmetry. Even if digital infrastructure is rapidly improved in the short term, if deep-seated institutional gridlock or the digital divide are not simultaneously addressed, the actual benefits may remain limited to marginal improvements (Yang & Wang, 2023). Conversely, empirical analysis shows that negative shocks such as cybersecurity incidents, policy fluctuations, or regional economic disruptions, even if of limited intensity, can trigger chain reactions of decline far exceeding expectations (Wu, Gao, & Feng, 2023). This phenomenon of 'amplified vulnerability' deeply reflects the structural defects of resource-based cities, slow progress, and high dependence on preconditions, but regression may accelerate due to institutional fragility and even evolve into a long-term development trap.

This study integrates path dependence theory and asymmetric shock theory to construct a new explanatory framework to reveal why internet development cannot be uniformly transformed into high-quality financial development. The core logic is that historical institutional legacies rigidly constrain growth paths, while the destructive power of negative digital shocks varies depending on local governance capabilities. For example, the

promotional role of internet infrastructure typically only fully manifests in cities that have crossed specific institutional thresholds. In regions that have not met these thresholds, even minor policy reversals or technological risk events may lead to stagnation or regression in financial innovation processes. Such complex dynamics are difficult to capture using traditional linear models. Therefore, this study employs a nonlinear autoregressive distributed lag (NARDL) model to more precisely capture the differentiated transmission mechanisms of positive and negative shocks.

This comprehensive framework enhances our understanding of how digital transformation occurs in resource-exhausted cities, emphasizing the roles of institutional readiness, historical pathways, and the nature of changes in shaping development outcomes. The theoretical framework is shown as Figure 2.

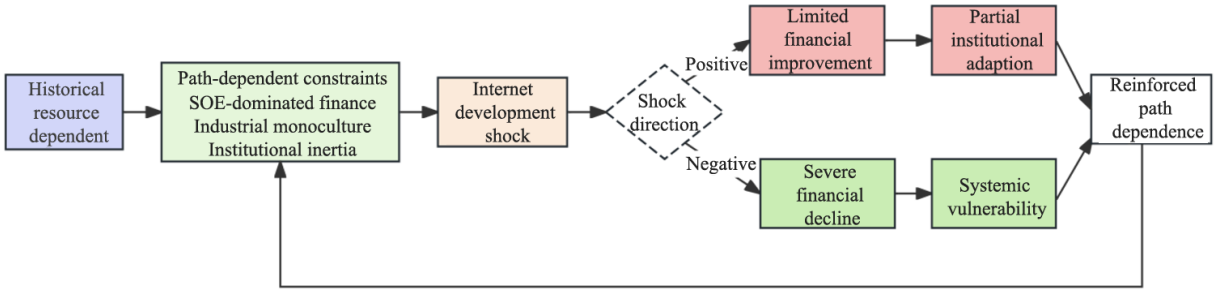

Figure 2. Theoretical model: Path dependence and asymmetric shocks in digital-financial interaction.

To clarify how the theoretical framework translates into empirical strategy, Table 2 maps the core concepts of Path Dependence Theory and Asymmetric Shock Theory onto the variables and modeling choices used in this study. This demonstrates that the selection of variables and the NARDL specification are not arbitrary but are rooted in the structural characteristics of Jiaozuo as a resource-exhausted city.

Table 2. Operational alignment between the theoretical framework and the econometric model.

Theory	Theoretical implication	Operationalization in model	Variable selection
Path dependence theory	Institutional inertia and historical trajectories delay or distort responses to new inputs.	Introduced via lagged variables in the NARDL model to capture cumulative/delayed effects.	Internet penetration R&D intensity per capita GDP
Asymmetric shock theory	Positive and negative external shocks have nonlinear and directionally different effects.	Decomposes Internet penetration into positive and negative components within the NARDL.	$Internet^{+}$ (Growth phase) $Internet^{-}$ (Contraction or disruption)

4. RESULTS

4.1. Data Description

The time series data utilized in this study were collected from the National Bureau of Statistics of China, China's regional financial reports issued by the People's Bank of China, and the WIND database. The analysis covers the period from 2000 to 2023. Due to some missing data points in the calculation of key variables, interpolation techniques were employed to estimate the missing values based on available data.

The Financial High-Quality Development index constructed in this study is grounded in China's "New Development Philosophy" outlined in the 14th Five-Year Plan. It reflects five core objectives: innovation, coordination, openness, and inclusiveness, which emphasize both the internal quality of financial activities and their contribution to broader structural transformation (Li, Dai, Lv, Xu, & Zhang, 2019; Shen & He, 2022). The construction of the high-quality financial development index in this study follows a multidimensional approach based on four key aspects. A total of nine indicators are selected to reflect both the internal performance of the financial system and its capacity to support broader economic development. Indicators related to innovation include R&D

investment as a share of GDP, the loan-to-deposit ratio, and the value-added share of the financial sector. Coordination is measured through rural fixed asset investment and the ratio of rural to urban per capita consumption. Openness is captured by the level of foreign direct investment and the number of financial institutions. Inclusiveness is assessed using per capita loan balances and the loan-to-GDP ratio (Table 3).

To minimize subjectivity in weighting, the entropy method is adopted. This data-driven approach not only reflects the informational contribution of each indicator but also ensures consistency with policy priorities and local financial structures. As a result, the HQFD index achieves a coherent integration of theoretical grounding and empirical measurement, particularly relevant to the structural conditions of resource-exhausted cities.

Table 3. Financial high-quality development index description.

Primary indicator	Secondary indicators	Descriptions	Directions	Source
Innovation	Innovation investment (%)	R&D internal expenditure/GDP	+	Henan Provincial Bureau of Statistics (2024) and People's Bank of China (2024)
	Financial efficiency (%)	Loan-to-deposit ratio	+	
	Financial sector economic density (%)	Financial sector value-added/GDP		
Coordination	Coordinated development input (%)	Rural fixed asset investment/GDP	+	
	Coordinated development output (%)	Rural-to-urban per capita consumption expenditure ratio	+	
Openness	Open development input (%)	FDI/GDP	+	
	Number of financial institutions	Number of financial institutions	+	
Inclusiveness	Inclusive development input (yuan)	Per capita loan balance	+	
	Financial depth (%)	Loan balance/GDP	+	

Internet penetration is the core independent variable in this analysis because it directly facilitates financial inclusion, lowers transaction costs, and promotes regional financial development (Evans, 2018). The internet penetration rate is calculated as the ratio of broadband subscribers (including multi-device accounts) to the resident population. Its multi-device characteristic, which can produce values greater than one, reflects the varying intensity of internet use in different contexts (Guiffard, 2024). This measure encompasses both supply-side aspects, such as access to digital banking services, and demand-side factors, including the adoption of Fintech solutions. As such, it provides a comprehensive indicator for investigating asymmetric effects within the NARDL framework.

Per capita GDP is included to account for regional economic development disparities as a control variable. As a fundamental indicator of economic capacity, it controls for the baseline resource availability that may jointly influence both internet penetration and financial development (Das, Chowdhury, & Seaborn, 2018). The logarithmic form is used to normalize its skewed distribution.

Trade openness, measured by the ratio of total trade to GDP as a control variable, serves as an indicator of a region's economic integration. It accounts for the influence of foreign exposure, which can independently drive financial sector advancement through the diffusion of technology (Tahir & Azid, 2015).

R&D intensity, defined as the ratio of internal R&D expenditure to GDP, represents the region's investment in innovation as a control variable. This metric, based on endogenous growth theory, addresses the institutional support for technological development that could potentially impact the relationship between internet usage and financial development (Savrul & Incekara, 2015).

4.2. Descriptive Analysis

The dataset (Table 4) indicates that internet penetration shows the greatest variability over time, with a mean of 0.636 and a range from 0.011 to 1.592. Financial high-quality development, in contrast, has a mean of 0.373 and displays moderate variation. R&D intensity is more concentrated over time, evidenced by a kurtosis of 4.666, while GDP per capita exhibits a left-skewed distribution, with a skewness of -0.750. Openness remains relatively stable over the periods analyzed. The temporal distribution of raw data underscores substantial variations in digital infrastructure, particularly internet penetration, compared to the more consistent investment in innovation captured by R&D intensity. Financial development indicators show moderate temporal differences, suggesting variations in the maturation of financial systems over time. The complete dataset, without any missing data, enables straightforward comparisons across all indicators throughout the time period studied.

Table 4. Descriptive analysis.

Variables	Financial high-quality development (Fin_Dev)	Internet penetration (Internet)	Per capita GDP Log (PGDP)	Openness (OP)	R&D intensity (RD)
Mean	0.373	0.636	10.358	0.089	0.015
Median	0.285	0.575	10.645	0.085	0.014
Maximum	0.856	1.592	11.221	0.152	0.028
Minimum	0.071	0.011	8.814	0.047	0.009
Std. Dev.	0.250	0.608	0.790	0.026	0.005
Skewness	0.447	0.390	-0.750	0.602	1.274
Kurtosis	1.800	1.561	2.156	2.783	4.666
Obs.	24	24	24	24	24

4.3. Model Formulation

The study adopts the Nonlinear Autoregressive Distributed Lag (NARDL) framework proposed by Shin, Yu, and Greenwood-Nimmo (2014) to examine the asymmetric effects of internet penetration on financial development. The NARDL model flowchart is shown as Figure 3.

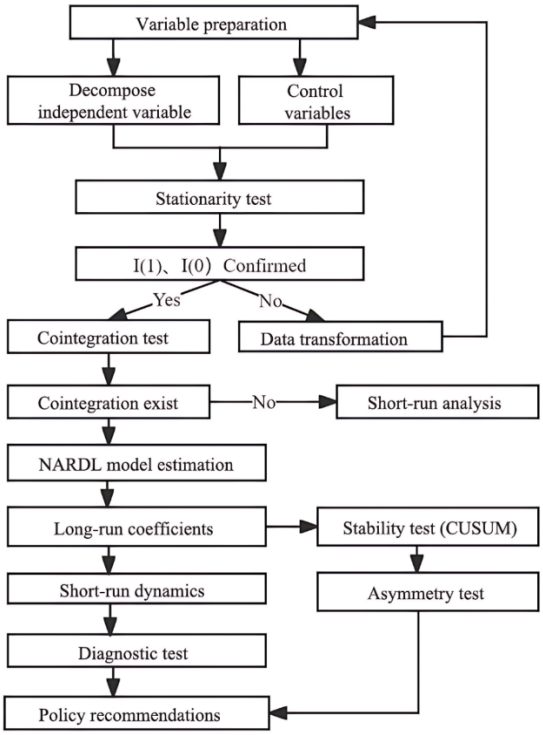

Figure 3. NARDL model flowchart.

The baseline econometric specification takes the following Equation 1 (Shin et al., 2014).

$$\Delta Fin\_Dev_t = \alpha_0 + \lambda_0 Fin\_Dev_{t-1} + \lambda_1^+ Internet_{t-1}^+ + \lambda_1^- Internet_{t-1}^- + \sum_{j=0}^{k} \delta_j Control_{j,t-1} + \sum_{i=1}^{p} \varphi_i \Delta Fin\_Dev_{t-i} + \sum_{i=0}^{q} (\beta_i^+ \Delta Internet_{t-i}^+ + \beta_i^- \Delta Internet_{t-i}^-) + \sum_{i=1}^{k} \sum_{m=0}^{s} \gamma_{i,m} \Delta Control_{i,t-m} + \varepsilon_t \quad (1)$$

where:

- Fin_Dev Represents the Finance High-Quality Development.
- $Internet^+$ and $Internet^-$ represent partial sums of positive and negative changes in internet penetration respectively.
- $Internet^+ = \Sigma \max(\Delta Internet_j, 0)$, $Internet_t^- = \Sigma \min(\Delta Internet_j, 0)$.
- The control vector includes: Ln (PGDP), OP, and RD.
- λ_1^+ measures the long-run elasticity of financial high-quality development to positive cumulative shocks in internet penetration, λ_1^- captures the long-run impact of negative cumulative shocks.
- β_i^+ and β_i^- respectively capture the immediate positive impact of current internet expansion and the negative effect on financial high-quality development.
- δ_j : Control Variables long-run equilibrium relationships.
- $\gamma_{i,m}$: Control Variables Short-term transitional effects.

The NARDL model provides several important benefits for this analysis. It allows for the identification of asymmetric effects by distinguishing between positive and negative changes in internet penetration, represented as $\Delta Internet^+$ and $\Delta Internet^-$. In addition, it can handle a mixture of stationary and non-stationary variables through bounds testing procedures.

Lastly, the model enables the estimation of both short-term dynamics and long-term equilibrium relationships within a single framework via the error correction mechanism. This makes the model particularly well-suited for exploring potential threshold effects and nonlinear dynamics in financial development (Shin et al., 2014). Considering the limited sample size, the study applies a cautious approach to lag order selection. The Schwarz Bayesian criterion guides the determination of optimal lags, with a maximum of 2 lags imposed across all variables to preserve model parsimony. The selected NARDL (1,1,0,2,2) specification successfully meets standard diagnostic requirements while maintaining stable coefficient estimates across alternative model specifications. This configuration aligns with economic reasoning and avoids the risk of over-parameterization, ensuring a parsimonious and theoretically sound model.

4.4. Stationarity Test

The stationarity of the variables was tested to verify their suitability for the NARDL model, which allows for variables to be either stationary at level or stationary after the first difference.

The results of the unit root tests in Table 5 showed that all variables are stationary after first difference. This confirms that the data meet the necessary conditions for applying the NARDL approach, supporting its use in the subsequent analysis.

Table 5. ADF test.

Variable	Level (t-statistic)	p-Value	1st difference (t-Statistic)	p-Value	Stationarity assessment
Fin_Dev	0.456	0.981	-4.238***	0.004	I(1)
Internet	0.082	0.957	-3.673**	0.012	I(1)
Ln(PGDP)	0.164	0.999	-4.252**	0.015	I(1)
OP	-2.194	0.214	-4.231***	0.004	I(1)
RD	1.097	0.996	-3.782***	0.010	I(1)

Note: The critical values are based on MacKinnon (1996) One-sided P-values, means at the 1% significance level, while ** indicates significance at the 5% level.

4.5. Bound Test

The F-statistic of 5.599 exceeds the upper critical bound of 4.193 for I(1) variables at the 5% significance level (Table 6). This provides clear evidence to reject the null hypothesis of no cointegration, confirming the presence of a statistically significant long-run equilibrium relationship among the variables (Pesaran, Shin, & Smith, 2001).

Table 6. Bounds test.

F-statistic	Significance level	I(0) Bound	I(1) Bound
5.599	10%	2.407	3.517
	5%	2.910	4.193
	1%	4.134	5.761

4.6. Model Estimation Result

The empirical results (Table 7) show that in terms of short-term dynamics, the impact of positive shocks to Internet penetration is significant (coefficient -0.476, p=0.033), and negative shocks produce a significant dampening effect (coefficient -2.048, p=0.017). This suggests that short-term expansion of digital infrastructure is difficult to immediately translate into financial development dividends, but service disruptions can immediately impair the operational efficiency of the financial system. The long-run equilibrium relationship presents more complex features: the positive cumulative effect of Internet penetration remains insignificant (coefficient -0.760, p=0.083), but the negative cumulative shock shows a significant contribution (coefficient 5.833, p=0.034). This seemingly contradictory result may stem from the special institutional environment of resource-exhausted cities, reflecting the possible systemic risk of over-digitization.

For economic growth (Ln(PGDP)), the long-term elasticity of 0.628 (p=0.014) confirms the endogenous growth hypothesis (Jones, 2019). However, the coefficient on short-term economic growth volatility does not reach the level of statistical significance. This difference implies that short-term economic fluctuations may influence financial high-quality development through non-GDP channels.

The exceptionally large coefficient for R&D Intensity (130.456, p=0.005) and the significant decline in the lagged coefficient (36.819, p=0.098) suggest that the benefits diminish as the initial technological implementation matures, supporting the hypothesis that the impacts of innovations change over time while emphasizing the need for sustained policy support to maintain the upgrading of the financial system (Elzen & Wieczorek, 2005). These findings suggest that strategic R&D allocation combined with supportive regulation can yield significant financial and high-quality development gains.

The empirical results derived from the NARDL model indicate that, in a resource-dependent city, Jiaozuo. The influence of openness on high-quality financial development exhibits a distinct long-term asymmetry. The model was optimized based on the Akaike Information Criterion (AIC), revealing that increases in openness do not have a significant short-term effect. However, its long-term impact is substantial, with a coefficient of 6.068 and a p-value of 0.057, suggesting a delayed but meaningful positive influence on financial development. This pattern can be attributed to Jiaozuo's unique economic structure, characterized by a credit market predominantly controlled by state-owned enterprises, and a relatively low reliance on foreign trade. These factors contribute to a lag in the transmission of openness-related policies, meaning that the full effects are only realized over an extended period.

The NARDL estimation reveals a significant error correction mechanism (ECM = -0.636, $p < 0.05$) for Jiaozuo's financial system, indicating rapid adjustment to long-run equilibrium at a 63.6% annual correction rate, with the model explaining 66.2% of development variance (adjusted $R^2 = 0.662$). These results demonstrate the distinctive resilience characteristics emerging from Jiaozuo's post-resource transition, where targeted financial reforms and regulatory adaptations have enhanced the city's capacity to absorb digitalization shocks while maintaining stable financial high-quality development trajectories.

Table 7. NARDL model estimation result.

Terms	Variables	Coefficient	P-Value
Cointegrating coefficients	$Ln(PGDP)_{t-1}$	0.628**	0.014
	RD_{t-1}	130.456***	0.005
	OP_t	6.068*	0.057
	$Internet_{t-1}^{+}$	-0.760*	0.083
	$Internet_{t-1}^{-}$	5.833**	0.034
	ECM_{t-1}	-0.636**	0.045
Short-term regression coefficients	$\Delta LN(PGDP)_{t-1}$	0.065	0.808
	D(RD)t	105.703***	0.003
	D(RD(-1))	36.819*	0.098
	$\Delta Internet_{t}^{+}$	-0.476**	0.033
	$\Delta Internet_{t}^{-}$	-2.048**	0.017
	$\Delta Internet_{t-1}^{+}$	-0.285	0.178
	$\Delta Internet_{t-1}^{-}$	-2.976**	0.025
	α_0	-5.062*	0.065
R-squared	0.882	F-statistic	4.009
Adjusted R-squared	0.662	Prob(F-statistic)	0.037

Note: ***,**,*means at the 1% ,5%,10% significance respectively.

4.7. Symmetry Test

The results of the symmetry tests (Table 8) indicate the presence of significant asymmetries in the effect of internet development on financial outcomes across both short- and long-term horizons. Specifically, the null hypothesis of symmetric response is strongly rejected for the long run, with an F-value of 16.890 and a p-value of 0.005, suggesting that positive and negative shocks to internet development elicit fundamentally different reactions in financial development. Similar evidence is observed in the short term, where the asymmetry test yields an F-value of 8.052 and a p-value of 0.025, indicating immediate effects that differ depending on the shock's direction. The joint test further confirms this pattern, with an F-value of 9.750 and a p-value of 0.010, demonstrating that the impact of internet development operates through distinct mechanisms depending on whether the shocks are positive or negative, as well as varying across different time horizons. Given that all p-values are below 0.05, these findings highlight the importance of utilizing nonlinear modeling strategies to accurately capture the complex relationship between internet development and financial growth.

Table 8. Coefficient symmetry tests.

Tested restriction	Test	Test statistic	P-value
Internet (Long-run)	F-statistic	16.890	0.005
	Chi-square	16.890	0.000
Internet (Short-run)	F-statistic	8.052	0.025
	Chi-square	8.052	0.005
Joint (Long-run and short-run)	F-statistic	9.750	0.010
	Chi-square	19.499	0.000

4.8. Model Diagnostics

4.8.1. Residual Normality Test

The Jarque-Bera test results (test statistic = 0.603, p-value = 0.740) indicate that the residuals are consistent with a normal distribution. These residuals show desirable characteristics: an almost zero mean, moderate variation (standard deviation = 0.028), and reasonable symmetry (skewness = 0.294) with kurtosis close to that of a normal distribution (kurtosis = 2.414). Collectively, these findings support the assumption of normality in the residuals, which is important for the validity of the model's coefficient estimates and inferences. Although not shown here, further checks for autocorrelation and heteroskedasticity would enhance confidence in the model's reliability (Figure 4).

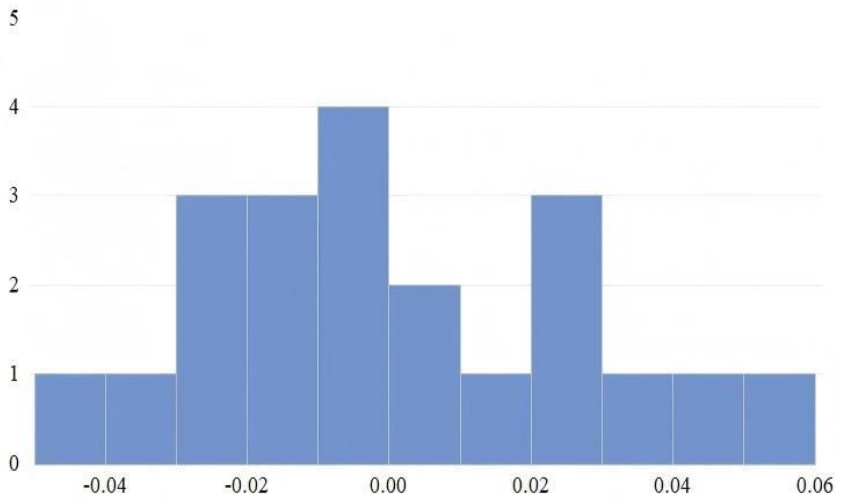

Figure 4. Normality test.

4.8.2. Heteroskedasticity Test

The Breusch-Pagan-Godfrey test results show an F-statistic of 0.944 with a p-value of 0.579, and an Obs*R-squared statistic of 15.521 with a p-value of 0.415 (Table 9). Since both tests fail to reject the null hypothesis of homoskedasticity at typical significance levels, there is no evidence of systematic heteroskedasticity in the residuals of the NARDL model.

Additionally, the scaled explained sum of squares (0.897, p = 1.000) supports this conclusion. Together with previous assessments of residual normality, these findings suggest that the model adheres to the key assumptions of classical linear regression, thereby validating the reliability of standard errors and inference.

Table 9. Heteroskedasticity test.

Heteroskedasticity test: Breusch-Pagan-Godfrey **Null hypothesis: Homoskedasticity**			
F-statistic	0.944	Prob. F(15,5)	0.579
Obs*R-squared	15.521	Prob. Chi-Square(15)	0.415
Scaled explained SS	0.897	Prob. Chi-Square(15)	1.000

4.8.3. Autocorrelation Test

The presence of significant first-order autocorrelation is indicative of the institutional features of Jiaozuo's financial system, where delays in policy implementation and predominant state involvement lead to predictable short-term responses.

This pattern illustrates how resource-depleted cities respond differently to digital shocks compared to more advanced regions, providing important insights into their specific financial behaviors. The autocorrelation observed aligns with the model specification, as it diminishes rapidly after the first lag, indicating that it captures short-term dynamics without indicating broader model misspecification.

These findings contribute to a deeper understanding of how transitional urban financial systems adapt to external shocks (Table 10).

Table 10. Autocorrelation test.

Autocorrelation Q-statistic probabilities adjusted for dynamic regressors				
lag	**AC**	**PAC**	**Q-Stat**	**Prob**
1	-0.410	-0.410	4.057	0.044
2	-0.077	-0.294	4.208	0.122
3	-0.109	-0.356	4.528	0.210
4	0.128	-0.188	4.995	0.288
5	-0.077	-0.255	5.174	0.395
6	0.048	-0.203	5.249	0.512
7	-0.087	-0.318	5.512	0.598
8	0.125	-0.232	6.088	0.637

Note: AC = autocorrelation; PAC = partial autocorrelation; Q-Stat = Ljung–Box Q statistic. Prob. reports p-values adjusted for dynamic regressors.

4.8.4. Stability Test

The stability of the NARDL model was evaluated using the CUSUM and CUSUMSQ tests based on recursive residuals (Figure 5). Both statistics remained within the 5% critical bounds across the sample period. This indicates that the estimated coefficients are stable over time and that the model does not suffer from structural breaks. These results support the validity of the estimated long-run and short-run relationships.

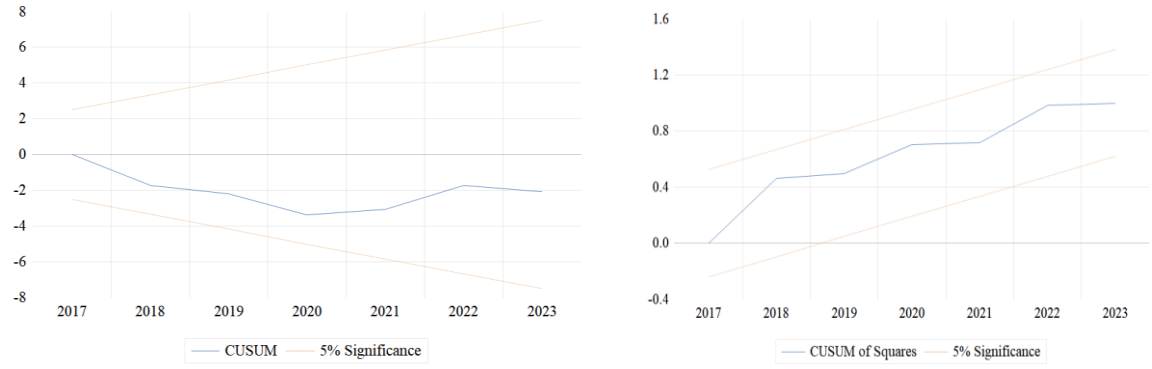

Figure 5. CUSUM and CUSUMSQ Test Results.

4.9. Cumulative Dynamic Multiplier Analysis

The analysis reveals that higher Internet penetration exerts a notable asymmetric inhibitory effect on high-quality financial development. In the short term (1-5 years), the expected positive impact of expanding digital infrastructure is not persistent. The long-term elasticity coefficient is negative (-0.760), indicating a clear directional trend, albeit not statistically significant. This suggests that digital expansion does not translate effectively into enhanced financial system quality. This issue is linked to the financial ecosystem of resource-dependent cities, where state-owned banks dominate the credit market and struggle to integrate digital technology. Consequently, rapid digital finance growth may crowd out resources from traditional financial institutions (Figure 6).

Meanwhile, the result indicates that a policy-driven, moderate contraction of Internet penetration has a positive moderating effect. The long-run elasticity coefficient is 5.833 (p=0.034), showing that controlling excessive digitization can unlock benefits from institutional improvements. This finding challenges the conventional belief that digitization always promotes financial development and highlights the threshold characteristics of digital financial growth in resource-driven contexts.

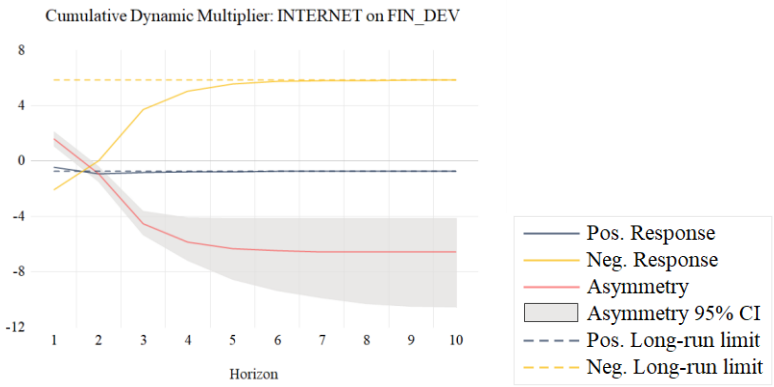

Figure 6. Cumulative Dynamic Multiplier: Internet on Fin_Dev.

5. DISCUSSIONS

5.1. Background and Gap

This study explores how internet development affects high-quality financial development in resource-depleted cities, focusing on Jiaozuo as a representative case. While earlier studies emphasize the benefits of digital infrastructure in improving financial access and efficiency (Gomber et al., 2018; Iwedi, 2024; Tian & Lu, 2023), most are based on more advanced or flexible regions. In contrast, this research shows how institutional rigidity, such as the dominance of state-owned enterprises, can limit the ability of digital tools to improve financial outcomes (Vagliasindi et al., 2022).

5.2. Key Findings

The NARDL model results point to three main findings. First, positive internet shocks do not significantly improve financial development in either the short or long run, suggesting that infrastructure investment alone is insufficient without institutional support (Ashfaq, 2024; Fagbemi & Kotey, 2024; Vagliasindi et al., 2022). This contrasts with more optimistic conclusions in the literature. Second, negative internet shocks have short-term negative effects but appear to support long-term improvements, possibly by triggering needed institutional adjustments. This supports research suggesting threshold effects and context dependence (Zhang et al., 2023). Third, complementary factors matter; R&D intensity shows a positive but diminishing impact, and economic openness exerts a delayed effect, consistent with findings from underdeveloped regions (Tian & Lu, 2023).

These empirical patterns differ in key respects from prevailing expectations in the literature. Much of the existing research assumes that digital expansion produces uniformly positive financial effects. However, this study finds that in the structurally constrained context of Jiaozuo, only negative digital shocks lead to meaningful long-term financial improvement. While counterintuitive, this result aligns with asymmetric shock theory, which emphasizes that economic responses to negative pressures can be stronger and more catalytic than responses to positive stimuli (Laguarda et al., 2020; McAleer et al., 2009). In the Jiaozuo case, digital contraction may have disrupted existing rigidities and prompted institutional adjustments that gradual expansion could not achieve. This interpretation is consistent with literature noting that structurally disadvantaged cities face institutional barriers to absorbing digital benefits. The absence of a significant positive effect may reflect the limited adaptive capacity of local financial institutions. These findings highlight the importance of institutional context and suggest that digital finance in resource-dependent cities does not follow the same trajectory as in more advanced settings.

5.3. Policy Implications

Based on these results, several policy implications emerge. This study demonstrates that the relationship between internet development and high-quality financial development in resource-exhausted cities is highly asymmetric, with

digital expansion generating uneven outcomes across different time horizons. Informed by the empirical evidence from Jiaozuo and aligned with the *National Sustainable Development Plan for Resource-Exhausted Cities* and the *14th Five-Year Plan for Digital Economy Development*, this section provides policy recommendations from both short-term and long-term perspectives, emphasizing institutional context, absorptive capacity, and adaptive reform sequencing.

In the short term (2025–2027), the priority should be to moderate the pace of digital expansion while laying a foundation for institutional resilience. According to the *National Sustainable Development Plan for Resource-Exhausted Cities*, transformation in these regions requires not only infrastructure input but also coordinated institutional adaptation. Therefore, local governments should refrain from pursuing indiscriminate internet infrastructure proliferation. Instead, comprehensive assessments of digital saturation and institutional readiness should be conducted, ensuring that internet penetration aligns with the actual capacity of the financial system to absorb and effectively utilize digital tools. This aligns with the study's finding that positive internet shocks do not immediately translate into financial gains in structurally constrained settings. Furthermore, echoing the Plan's call to "strengthen human capital and service capacity", targeted digital financial literacy programs should be developed for SMEs and rural residents. These initiatives will help bridge the usage gap and prepare users for more complex forms of financial intermediation.

Meanwhile, policymakers should also introduce flexible buffer mechanisms to manage the risks associated with over-digitization. Drawing inspiration from the *14th Five-Year Plan* for Digital Economy Development, which emphasizes "secure, orderly, and inclusive digital growth," local authorities may establish temporary regulatory easing zones or phase-in pilot policies that allow gradual adaptation by local financial actors. This is particularly important in cities like Jiaozuo, where sudden digital shifts could destabilize an already fragile institutional foundation. Such transitional zones can reduce adjustment costs while preserving the intended momentum of digital reform.

In the long term (2028–2035), policy efforts should focus on structural realignment between digital development and financial governance. The *Sustainable Development Plan* advocates for the diversification of urban economies and the modernization of service sectors in resource-exhausted regions. Consistent with this objective, digital finance expansion must be embedded within broader institutional reform agendas. This includes increasing the credit autonomy of non-state financial institutions, breaking the dominance of state-owned banks in resource allocation, and updating regulatory tools to monitor and guide digital finance innovation. Only through this structural coordination can the benefits of internet penetration be fully realized.

Moreover, the long-term success of digital financial development in cities like Jiaozuo depends on adopting threshold-based policy frameworks, as promoted by the *14th Five-Year Plan*. This means that financial support, digital licensing, and infrastructure investment should be tied to measurable indicators such as financial literacy levels, SME participation in digital services, or internet infrastructure utilization rates. Such conditionality ensures efficient resource allocation and guards against premature or misaligned expansion. At the same time, sustained public investment in digital innovation ecosystems, including university-industry collaboration platforms, digital finance incubators, and R&D incentives for regionally customized technologies, will be vital to building local absorptive capacity and reducing path dependence.

5.4. Limitations and Future Research

While this study offers context-rich insights into the dynamics of digital finance in resource-dependent settings, a few considerations suggest directions for further refinement. The focus on a single city provides analytical depth but leaves open questions about how broadly the findings may apply to other regions. The sample structure, shaped by data availability, may also influence the sensitivity of estimated effects. Moreover, future work could benefit from incorporating spatial dynamics or firm-level behavior to further enrich the understanding of digital-financial interactions in diverse institutional environments.

Future research could expand the sample scope to include resource-based cities with different characteristics for comparative analysis, thereby testing the applicability of the research conclusions. It is recommended to use spatial econometric methods to examine the regional linkage effects of digital finance development. At the same time, enterprise-level data could be used to analyze the impact mechanism of digitalization on financial development under different institutional environments.

6. CONCLUSIONS

This study demonstrates that the relationship between internet development and high-quality financial development in resource-exhausted cities is highly asymmetric, with digital expansion generating uneven outcomes across different time horizons.

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