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DOES THE DIGITAL ECONOMY PROMOTE SUSTAINABLE INTEGRATED URBAN-RURAL DEVELOPMENT? EVIDENCE FROM CHINA

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Abstract. Using panel data from 30 Chinese provinces from 2013–2022, this study examines the role of the digital economy in advancing Urban-Rural Integration (URI). Our results demonstrate that the digital economy has a significant effect on URI, even after accounting for potential endogeneity and conducting robustness tests. Mediation analysis finds that industrial upgrading and marketization serve as key channels through which the digital economy boosts integration. Moderation analysis reveals that fiscal support for agriculture strengthens the positive impact, while rising urbanization tends to weaken it. The threshold analysis indicates that the impact of the digital economy is nonlinear. It promotes integration at early and intermediate stages, but its marginal effect decreases once development surpasses a threshold value. Further analysis shows that the digital economy most strongly influences social integration, followed by economic, ecological, and spatial integration. Additionally, the positive role of digital development is more evident in China's central and western regions than in the east. These results offer policy insights on leveraging digital transformation to foster more equitable and sustainable urban-rural development.

Keywords: digital economy, urban-rural integration, industrial upgrading, marketization, fiscal support, urbanization, nonlinear effects.

JEL Classification: O18, O33.

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1. Introduction

Urban-rural relations are fundamental to a country's socioeconomic structure, and managing this relationship is key to socialist modernization (Zhao, 2020). Since the 16th National Congress of the Communist Party of China (CPC), China's strategy has gradually shifted from simply "balancing" urban and rural development to pursuing full "integration". This transformation reflects both current development needs and Marxist theory. Unlike previous policies, integrated development seeks to break down the urban-rural divide. As such, it is a core tool for reducing regional disparities and aiding rural development (Wei et al., 2021), serving as a critical stepping stone for Chinese-style modernization.

Historically, China's economic expansion has been predominantly urban-centric. While this approach has supported rapid growth, it exacerbated the urban-rural divide, resulting in income inequality, industrial imbalances, and impeded factor mobility (Li et al., 2022). Currently, the advent of a new technological revolution – characterized by digitalization, intelligence,

and connectivity – offers new drivers for rural transformation. These advancements present unprecedented opportunities to accelerate URI. Therefore, examining the role of the digital economy in the integration process is essential for reshaping urban-rural relationships.

Policy attention to URI has intensified following its formal elevation at the 19th CPC National Congress in 2017. Subsequent policy initiatives, including the “No.1 Central Document” of 2024, have reinforced the imperative of fusing rural industries and promoting county-level coordination. Parallel to these policy shifts, research on URI has grown rapidly. Scholars have developed comprehensive index systems to evaluate integration spanning economic, social, spatial, ecological, and demographic dimensions, employing methodologies such as the Analytic Hierarchy Process (Yang et al., 2021), Principal Component Analysis (Liu & Lu, 2019), and the Entropy Weight Method (Cheng et al., 2023). Although the general consensus points to an upward trend, studies frequently highlight persistent inefficiencies (Shi et al., 2021) and the paradox where economically advanced regions do not necessarily exhibit superior integration performance (Wang & Zhao, 2022). The existing literature identifies institutional arrangements (Wu et al., 2022), resource allocation (Cao et al., 2024), public service provision (Chen et al., 2024), and technological innovation (Wang et al., 2023b) as key determinants of integration outcomes.

Following the agricultural and industrial eras, the digital economy ushers in a new stage of economic evolution. It holds the potential to break down geographical barriers, accelerate the flow of production factors and foster shared prosperity. The concept, popularized by Tapscott (1997), broadly encompasses economic activities powered by ICT. Current scholarship on this topic centers on three primary dimensions: measurement, development patterns, and impacts. In terms of measurement, scholars employ diverse methodologies from value-added calculations to satellite accounts (Nicholson et al., 2023). Turning to digital economy development patterns, according to 2022 estimates by the China Academy of Information and Communications Technology [CAICT], (2023), the digital economy across 51 major countries totaled \$41.4 trillion, representing 46.1% of their combined GDP. However, significant regional divides persist. While North America and Europe lead in terms of digital infrastructure, innovation ecosystems, and market digitalization (Benedetti et al., 2023), emerging economies are catching up – notably with China exceeding 40% of GDP in 2023 (CAICT, 2024) and India witnessing an e-commerce boom (Khan, 2022). Conversely, regions like Africa and parts of Latin America continue to face development lag (Abendin & Duan, 2021). Finally, the literature also focuses on the digital economy’s impacts. Digitalization is widely recognized as a driving force for enhancing productivity (Wang et al., 2020), but it simultaneously triggers structural disruptions in labor markets and industrial organization (Acemoglu & Restrepo, 2021; Dauth et al., 2021; Kolade & Owoseni, 2022).

Existing research on the link between digital development and URI can be broadly grouped into three strands. First, a large body of work investigates specific outcomes like economic integration (Tai & Cai, 2022) or rural industry integration (Zhang et al., 2024). While these studies offer valuable insights, relatively few studies provide a comprehensive assessment of how digital development influences URI as a whole. On transmission channels, scholars have identified various transmission mechanisms, including rural financial services (Xiong & Dai, 2024), human capital investment (Wang et al., 2023a), urban-rural employment (Jiang & Jin, 2024), factor flows (Peng & Dan, 2023), resource allocation (Lu et al., 2025b), and public

service equalization (Liu & Ma, 2024). Nevertheless, the aggregate impact remains hotly debated. Some scholars argue that digital technologies generate a “digital dividend” that unifies markets (Guo & Su, 2023; Wu & Shao, 2022), while others caution against a “digital divide” where uneven infrastructure deepens exclusion (Parks et al., 2022). More nuanced perspectives propose nonlinear relationships, suggesting that the benefits of digitalization may follow an inverted U-shape or vary by development stage (Zhang & Shan, 2023). Additionally, a growing body of work incorporates spatial analytical methods to examine how digital development affects URI through interregional spillover effects (Lu et al., 2025a).

This study makes four key contributions relative to existing research. First, we develop a holistic multidimensional framework – covering economic, spatial, social, and ecological dimensions – to address the limitations of single-dimension assessments. Second, we explicitly examine industrial upgrading and marketization as mediating mechanisms, while also accounting for the moderating effects of fiscal support for agriculture and urbanization. In addition, we employ a panel threshold regression method to capture the nonlinear impacts brought about by the digital economy, thereby gaining a deeper understanding of the influence of the digital economy on URI at different stages. Finally, we provide a detailed examination of heterogeneity, both across the sub-dimensions of URI and across regions, shedding light on spatially differentiated effects amid China’s diverse development context.

2. Theoretical analysis and research hypotheses

The digital economy drives URI through the following aspects. Economically, digital technologies boost market connectivity, elevate agricultural productivity and reduce barriers to rural entrepreneurship, which helps narrow income and consumption gaps (Gong et al., 2023). Socially, the widespread application of digital technology in public services sectors allows rural students to access high-quality educational resources and enables rural residents to receive advanced medical care (Hu et al., 2022; Wen, 2022). Moreover, the digitization of social security systems streamlines access to essential services, enabling rural residents to manage pensions, insurance, and welfare benefits via online platforms. Spatially, digital technologies reshape the physical and functional relationships between cities and rural areas. By leveraging information technologies, digitalization enhances agricultural production, rural logistics, and social governance, effectively compressing both physical and informational distances (Faxon, 2022). Ecologically, the digital economy provides innovative tools for coordinated environmental management. Technologies like smart sensors enable real-time environmental monitoring, improving the efficiency of environmental governance (Deng et al., 2023b). Based on the above analysis, this study proposes the following hypothesis:

H1: *The digital economy has a positive impact on URI.*

The digital economy influences URI not only through direct effects, but also by transforming regional industrial structures. Enabled by emerging digital technologies, firms are increasingly shifting from traditional production models to more intelligent and data-driven manufacturing processes, which simultaneously improves productivity and reduces operating costs. Concurrently, new service sectors – including e-commerce, live streaming, and the sharing economy – have expanded rapidly, profoundly reshaping consumption patterns and

market structures (Su, 2022), while stimulating the growth of supporting industries including logistics, digital finance, and smart infrastructure. In this process, industrial upgrading serves as a key bridge between urban and rural areas. Through digital platforms, rural specialty products and tourism resources can now be more effectively connected to urban markets, forming complementary industrial chains (Chi & Shi, 2022). While rural products gain access to broader markets through e-commerce, urban capital, technology, and management expertise flow into rural tourism and related industries, supporting their development. As industrial structures become more advanced and interconnected, the economic foundation for URI is strengthened (Liu & Chen, 2021). Based on this mechanism, we propose:

H2: *The digital economy promotes URI by accelerating industrial upgrading.*

Marketization reflects the degree to which market mechanisms regulate resource allocation and economic activities in a region (Sun et al., 2022). The widespread adoption of digital technology fosters a more efficient market environment by establishing digital government service platforms to streamline administrative approvals, leveraging big data analytics to regulate emerging digital industries, and refining legal and regulatory frameworks to protect digital intellectual property. Furthermore, technological advancements have enabled more accurate matching between market supply and demand, reducing resource waste, and improving overall market efficiency (Wang et al., 2021). As marketization progresses, enterprises and workers in rural areas gain more equitable access to markets, which significantly unlocks the development potential of the rural economy. Additionally, by lowering spatial and informational barriers, digital development facilitates smoother flows of labor and capital. Consequently, improvements in marketization further strengthen URI (Shi et al., 2023). Therefore, we propose:

H3: *The digital economy promotes URI by enhancing the level of marketization.*

Based on the above theoretical arguments and Hypotheses 1–3, the interconnections among digital economy, industrial upgrading, marketization, and URI are summarized in Figure 1.

Government fiscal support for agriculture serves as a key institutional mechanism for aligning rural development with urban expansion. By directing capital toward rural digital infrastructure, public expenditure not only enhances information accessibility but also extends the digital economy's footprint into less developed peripheries areas, thereby narrowing the

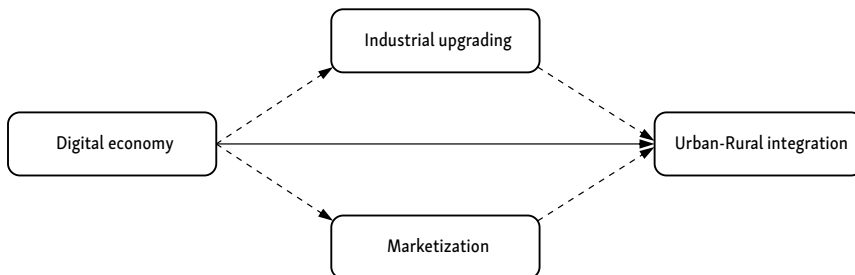


Figure 1. Analytical framework illustrating the mediating roles of industrial upgrading and marketization

digital gap (Zhang, 2023). Moreover, targeted government fiscal support incentivizes the diffusion of advanced technologies, boosting the efficiency and modernization of agricultural production (Liu & He, 2023). Beyond economic aspects, fiscal investment also helps support rural social welfare. Specifically, government investments play a pivotal role in upgrading rural social services, particularly through digital platforms that offer telemedicine, online education, and digital social security services. These initiatives expand service availability in rural areas, enhance living standards, and reinforce the sustainability of rural communities (Zhang & Fang, 2023). Thus, we propose:

H4: *Fiscal support for agriculture positively moderates the impact of the digital economy on URI.*

Rapid urbanization often generates a strong agglomeration effect, channeling investment, infrastructure, and high-quality public services primarily into urban centers (Huang & Zhao, 2023). Conversely, the accompanying rural-to-urban labor outflow precipitates population aging and rural workforce “hollowing out”, eroding the inherent economic vitality of the rural areas. In the context of digital economy, essential endowments – technology, capital, and digital literacy – are highly sensitive to this urban bias. Given that urban hubs boast superior digital infrastructure and innovation capabilities, rural regions frequently grapple with structural deficiencies that hinder effective technological adoption (Xia, 2021). As a result, higher levels of urbanization may exacerbate the digital asymmetry rather than bridge it, widening the relative disadvantage of rural sectors. This trend indicates that excessive urban concentration can diminish the inclusive benefits of digitalization. Therefore, we propose:

H5: *Urbanization has a negative moderating effect on the positive impact of the digital economy on URI.*

Drawing on Hypotheses 4–5, the interactions among the digital economy, fiscal support for agriculture, urbanization, and URI are summarized in Figure 2.

Endogenous growth theory (Romer, 1990) and innovation diffusion theory (Arthur, 1989) suggest that the adoption of technology and its externalities are highly stage-dependent. Consequently, the influence of the digital economy on sustainable URI is inherently dynamic and depends on the level of digital development (Huang & Wang, 2022; Shi et al., 2023). In the initial stage, deploying digital technologies primarily serves to build essential information linkages. By dismantling traditional barriers to factor circulation and reducing transaction costs, early-stage digitalization rapidly bridges the digital divide, thereby delivering a robust

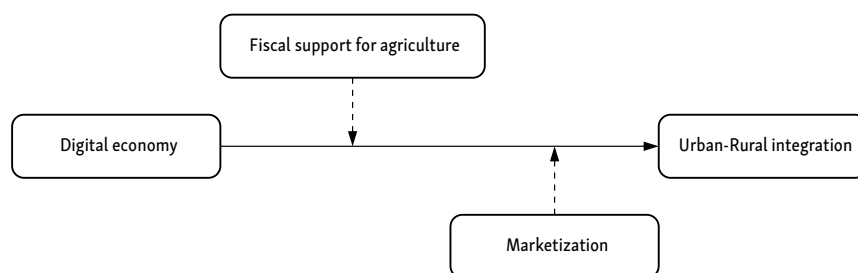


Figure 2. Moderating effects in the relationship between the digital economy and URI

boost to URI (Deng et al., 2023a). As digitalization enters a moderate stage, the marginal gains from basic digital infrastructure gradually diminish, while structural disparities in digital skills and industrial integration become more pronounced (Lu et al., 2025a). At advanced stages, if digital expansion prioritizes scale over quality and inclusiveness, it may be insufficient to correct deep-rooted spatial imbalances, weakening of its integrative impact (Peng & Dan, 2023). Based on this non-linear dynamic, we propose:

H6: *The impact of digital economy development on the sustainable URI exhibits threshold effects.*

3. Materials and methods

3.1. Data source

This study employs panel data from 30 Chinese provinces (excluding Tibet, Hong Kong, Macao, and Taiwan) or the period 2013 to 2022. The dataset is compiled from various official sources, including the *China Statistical Yearbook*, *China Population and Employment Statistical Yearbook*, *China Rural Poverty Monitoring Report*, *Peking University Digital Financial Inclusion Index*, and the EPS database. Missing observations were supplemented using official statistical bulletins released by provincial governments.

3.2. Variable selection

3.2.1. Explained variable: urban-rural integration (URI)

The Urban-Rural Integration (URI) is taken as the explained variable. In line with the research objectives, this study constructs a comprehensive evaluation system.

Urban-Rural Economic Integration (UREI) focuses on aligning development outcomes and living standards to pursue shared prosperity (Xie & Han, 2022). The selected indicators include the duality comparison coefficient, the ratio of per capita income, and the ratio of per capita consumption. The duality comparison coefficient reflects structural differences between urban and rural industrial productivity, where the primary sector is dominated by rural areas and the secondary and tertiary sectors concentrated in urban areas (Luo et al., 2023). Although it does not directly measure interaction, it effectively reflects structural imbalances. Combined with income and consumption indicators, these measures jointly capture both productivity gaps and welfare convergence, providing a more comprehensive assessment of economic integration (Zhang et al., 2024).

Beyond economic disparities, Urban-Rural Social Integration (URSI) emphasizes the equitable distribution of public resources, addressing institutional gaps in education, healthcare, and social security (Zhou & Fang, 2023). To measure this dimension, we select indicators representing the parity of urban-rural medical insurance, education expenditure, and pension coverage. These metrics proxy for the removal of institutional barriers, reflecting the harmonization degree of social security and public service systems (Wang et al., 2023a; Zhan et al., 2023).

Urban-Rural Spatial Integration (URPI) focuses on dismantling physical barriers to ensure the smooth circulation of production factors (Deng et al., 2023a). To measure spatial

integration, we measure this dimension using road network density, population interaction, and network connectivity (Cheng et al., 2023; Shi et al., 2021; Wang & Zhao, 2022). Road network density captures the level of physical connectivity between urban and rural areas (Cheng et al., 2023), while population interaction intensity and network connectivity reflect the intensity of cross-regional exchanges and the efficiency of service and factor flows (Gao et al., 2025).

Urban-Rural Ecological Integration (URCI) involves the coordination of environmental quality and functions (Xue et al., 2023). We evaluate indicators such as environmental protection intensity, green space development level, and living environment management (Cao et al., 2024; Hu & Qi, 2022; Wang et al., 2023b). The urban household waste treatment rate reflects the environmental governance capacity of cities, with their infrastructure and practices often extended to rural areas, driving ecological improvements (Cao et al., 2024; Liu & Ma, 2024). When combined with green space metrics, these indicators capture the extent of cross-regional ecological coordination and complementarity.

Table 1. Indicator system for measuring URI

Primary Index	Secondary Index	Index calculation method	Attribute
UREI	Duality comparison coefficient	Output per worker in the primary industry / output per worker in the secondary and tertiary industries	Positive
	Per capita income ratio	Urban residents' per capita wage income / rural residents' per capita wage income	Negative
	Per capita consumption ratio	Urban residents' per capita consumption expenditure / rural residents' per capita consumption expenditure	Negative
URSI	Medical Security	Hospital beds per 1,000 people in urban areas / hospital beds per 1,000 people in rural areas	Negative
	Education spending	Urban per capita education, culture, and entertainment spending / rural per capita education, culture, and entertainment spending	Negative
	Pension coverage rate	Population covered by basic pension insurance / total population	Positive
URPI	Road network density	(Road mileage + railway mileage) / land area	Positive
	Population interaction	Total passenger turnover (billion passenger-kilometers)	Positive
	Network connectivity intensity	Urban per capita transport and communication expenditure / rural counterpart	Negative
URCI	Environmental protection effort	Environmental protection expenditure / local general fiscal expenditure	Positive
	Greening and beautification	Urban green coverage rate in built-up areas	Positive
	Living environment management	Urban household waste treatment rate	Positive

Note: "Positive" indicates that a higher value of the indicator corresponds to a higher level of URI; "Negative" indicates the opposite.

Based on the selected indicators, this study employs the entropy weighting method to construct a composite index of URI. We categorize indicators as “Positive” (where higher values indicate better integration outcomes) or “Negative” (where higher values indicate poorer integration). We normalize all variables using the min-max method to eliminate scale differences, and then calculate entropy values and corresponding weights to construct a composite index of URI. This method allows for objective weight assignment while maintaining comparability across diverse indicators. The indicator system is summarized in Table 1, and the detailed computational procedures for the entropy method are provided in Appendix A.

3.2.2. Explanatory variable: the digital economy index (DEI)

To measure the development of the digital economy, this study constructs a comprehensive provincial-level index based on established empirical frameworks. The Digital Economy Index (DEI) consists of five dimensions in this paper. Digital infrastructure reflects the regional network accessibility and digital readiness, and we proxy it by the density of internet access ports per 10,000 people (Huang & Wang, 2022). Digital industrialization captures the direct economic output of the ICT activities. Its indicators can be measured by per capita software business revenue (Hu et al., 2022). Industrial digitalization represents the penetration of digital technologies into traditional sectors, and we use the proportion of enterprises engaged in e-commerce as a proxy (Zhang et al., 2023). Digital governance signifies the modernization of public administration and is measured by the density of government internet access ports (Yang & Jiang, 2021). Digital innovation captures a region's ability in the application and promotion of digital technologies, using the Digital Inclusive Finance Index as a proxy (Zhao et al., 2022). Detailed formulas are provided in Appendix A.

3.2.3. Mediator variables

Following the theoretical framework, we examine two mediating channels. Industrial Upgrading (INU) reflects the structural evolution of regional economies toward higher value-added and technology-intensive activities, serving as a key channel linking digital development with integrated growth (Wang et al., 2022). Marketization (MAR) captures the institutional environment governing market-oriented resource allocation and is widely recognized as a fundamental driver of factor mobility and regional integration (Fan et al., 2011).

3.2.4. Moderator variables

This paper introduces two moderating variables. Specifically, Fiscal Support for Agriculture (FSA) represents the intensity of government intervention in rural development, which is expected to alleviate infrastructure and service constraints (Guo & Chi, 2023). Urbanization (URB) reflects demographic concentration and spatial restructuring. We include this variable to assess whether urban expansion strengthens or weakens the inclusiveness of digital-driven integration (Cheng & Liu, 2023).

3.2.5. Control variables

We include a set of control variables to isolate the core relationship (Cao et al., 2024; Chen et al., 2023, 2024; Wang et al., 2023a; Wu et al., 2022). Specifically, we account for Technological

Innovation Level (TIL), Agricultural Modernization Level (AML), Land Use Intensity (LUI), Rural Human Capital (RHC), and Financial Development Level (FDL).

Definitions and measurement methods for all variables are reported in Table 2, while descriptive statistics are presented in Table 3.

Table 2. Variable type, symbol, variable name, and calculation method

Variable type	Variables	Calculation method
Explained variable	URI	Composite index
Explanatory variable	DEI	Composite index
Mediator variables	INU	Tertiary industry value added / national economic value added
	MAR	Provincial marketization index
Moderator variables	FSA	Fiscal expenditure on agriculture / total fiscal expenditure
	URB	Urban population / total population
Control variables	TIL	Logarithm of R&D expenditure of industrial enterprises above designated size
	AML	Logarithm of total power of agricultural machinery
	LUI	Built-up area / total land area
	RHC	Average years of education in rural areas
	FDL	Logarithm of regional financial industry value added

Table 3. Descriptive statistics of variables

Variables	Obs	Mean	Std. Dev.	Min	Max
URI	300	0.63	0.076	0.396	0.796
UREI	300	0.505	0.108	0.243	0.861
URSI	300	0.699	0.118	0.386	0.927
URPI	300	0.494	0.133	0.150	0.779
URCI	300	0.606	0.103	0.160	0.981
DEI	300	0.313	0.147	0.027	0.766
INU	300	0.495	0.091	0.320	0.839
MAR	300	8.352	1.882	3.580	12.860
FSA	300	11.451	3.447	4.040	20.380
URB	300	0.614	0.114	0.380	0.900
TIL	300	14.519	1.363	11.08	17.29
AML	300	7.693	1.137	4.54	9.500
LUI	300	0.022	0.036	0.00	0.196
RHC	300	7.746	0.839	3.800	9.910
FDL	300	7.314	0.928	4.550	9.380

Note: Obs = number of observations; Std. Dev. = standard deviation.

3.3. Methods

3.3.1. Baseline model

Following the empirical framework widely adopted in the literature (Opler et al., 1999), this study specifies the baseline model as follows:

$$URI_{it} = \alpha_0 + \alpha_1 DEI_{it} + \alpha_2 control_{it} + \varepsilon_{it}. \quad (1)$$

In Eq. (1), i and t represent the province and time respectively. URI_{it} denotes the degree of regional integration. DEI_{it} represents digital economy index. $control_{it}$ is the set of control variables affecting URI. ε_{it} denotes the error term. If α_1 in Eq. (1) is significant, then Hypothesis 1 is validated.

3.3.2. Mediation model

This study adopts the stepwise mediation analysis framework developed by Baron and Kenny (1986) and Wen and Ye (2014). Industrial upgrading (INU) and Marketization (MAR) are introduced as mediating variables. The empirical models are formulated as follows:

$$mediator_{it} = \beta_0 + \beta_1 DEI_{it} + \beta_2 control_{it} + \varepsilon_{it}; \quad (2)$$

$$URI_{it} = \gamma_0 + \gamma_1 DEI_{it} + \gamma_2 mediator_{it} + \gamma_3 control_{it} + \varepsilon_{it}. \quad (3)$$

In Eqs. (2)–(3), $mediator_{it}$ denotes either INU or MAR. The coefficient α_1 in Eq. (1) captures the total effect, γ_1 represents the direct effect, and the product $\beta_1\gamma_2$ reflects the indirect (mediated) effect. Accordingly, the total effect can be decomposed as $\alpha_1 = \gamma_1 + \beta_1\gamma_2$, and the magnitude of the mediation effect is measured by $M_{M,J} = \beta_1\gamma_2/\gamma_1$. To identify the presence of mediation, we first examine whether α_1 in Eq. (1) is statistically significant. Conditional on this requirement being satisfied, a stepwise procedure is employed to assess the significance of β_1 and γ_2 . If both β_1 , γ_2 are significant, Hypotheses 2–3 are supported. If either coefficient is insignificant, Sobel and Bootstrap tests are subsequently applied to ascertain if the indirect effect remains statistically significant.

3.3.3. Moderation model

To explore the moderating effects of Fiscal Support for Agriculture (FSA) and Urbanization (URB), an interaction term analysis method was employed. Extending Eq. (1), the moderation model is given by:

$$URI_{it} = \theta_0 + \theta_1 DEI_{it} + \theta_2 DEI_{it} * moderator_{it} + \theta_3 moderator + \theta_4 control_{it} + \varepsilon_{it}. \quad (4)$$

In Eq. (4), $moderator_{it}$ represents either FSA or URB. the interaction term $(DEI_{it} * moderator_{it})$ represents the moderating effects. A statistically significant coefficient θ_2 indicates the presence of moderation, thereby providing empirical support for Hypotheses 4–5.

3.3.4. Threshold model

To capture potential nonlinearities, we apply the panel threshold regression model proposed by Hansen (1999). This approach allows the threshold value to be endogenously determined by minimizing the residual sum of squares. The statistical significance of the threshold effect is assessed using bootstrap methods, while confidence intervals are obtained via Likelihood

Ratio (LR) tests. The corresponding specification is given by:

$$URI_{it} = \lambda_0 + \lambda_1 DEI_{it} \cdot I(DEI_{it} \leq q) + \lambda_2 DEI_{it} \cdot I(DEI_{it} > q) + \lambda_3 control_{it} + \varepsilon_{it}. \quad (5)$$

In Eq. (5), $I(\cdot)$ is an indicator function. q is the estimated threshold. The coefficients λ_1 and λ_2 represent the effects of the digital economy across different regimes. A significant difference between these coefficients indicates a structural change in the relationship, providing empirical support for Hypothesis 6.

4. Empirical results

4.1. Baseline regression results

Prior to regression analysis, we verified the distributional properties of the panel data. Both LLC and Fisher-ADF tests rejected the null hypothesis of unit roots at the 1% level, indicating that all the series were in a stationary state. Furthermore, VIF statistics remained consistently below the threshold of 5, dismissing concerns regarding multicollinearity. Detailed test results are reported in Appendix Tables B1–B2.

This study applies Eq. (1) to estimate the baseline effect, with the corresponding results presented in Table 4. In column (1), DEI has a coefficient of 0.214, statistically significant at the 1% level, providing initial proof that digital economy drives URI. Subsequently, we add control variables (TIL, AML, LUI, RHC, and FDL) from Columns (2)–(6). Notably, the DEI coefficient remains stable in both magnitude and significance, confirming that the baseline result is robust to the inclusion of potential confounding factors. At the same time, the model's explanatory power improves steadily, with the R^2 increasing from 0.373 in column (1) to 0.613 in column (6), suggesting enhanced model fit. Overall, these findings align with recent literature (Chen et al., 2023; Zhan et al., 2023), providing strong preliminary support for Hypothesis 1.

Furthermore, as shown in column (6), TIL, AML, and RHC all positively contribute to URI, consistent with the findings of existing research (Huang & Wang, 2022; Tai & Cai, 2022; Wu et al., 2022). By contrast, FDL is negatively related to URI. This suggests structural weaknesses in rural financial systems, including limited service coverage and insufficient financial products to meet rural financing needs (Wang et al., 2023a).

Despite the robust baseline results, potential endogeneity remains a concern. To address this, we employed a 2SLS approach, with results reported in Table 5. Following Bai and Yu (2021), columns (1)–(2) use the interaction between the number of fixed telephones per 100 people in 1984 and the lagged number of internet access ports as the first Instrumental Variable (IV1). The coefficient of IV1 is 0.099, and the coefficient of DEI is 0.199, both statistically significant. The estimates show that IV1 is significantly related to DEI, and the second-stage results continue to indicate a positive and significant effect of the digital economy on URI. For robustness, we adopt the first lag of the digital economy as an alternative instrument (IV2), referencing Huang and Wang (2022). The corresponding results, reported in columns (3) and (4), remain statistically significant. In addition, under-identification and weak identification tests confirm the relevance and strength of the instruments. Overall, the 2SLS estimates are consistent with the baseline results, further reinforcing Hypothesis 1.

Table 4. Baseline regression results

Variables	Dependent variable: URI					
	(1)	(2)	(3)	(4)	(5)	(6)
DEI	0.316*** (13.314)	0.218*** (8.227)	0.302*** (12.130)	0.285*** (11.299)	0.288*** (11.483)	0.341*** (11.158)
TIL		0.019*** (6.735)	0.008*** (2.753)	0.016*** (4.058)	0.015*** (3.770)	0.029*** (4.697)
AML			0.027*** (9.467)	0.015*** (2.973)	0.016*** (3.273)	0.018*** (3.598)
LUI				−0.447*** (−2.950)	−0.412*** (−2.722)	−0.227 (−1.402)
RHC					0.008** (2.249)	0.007** (2.232)
FDL						−0.031*** (−2.954)
CONSTANT	0.531*** (64.637)	0.281*** (7.425)	0.218*** (6.418)	0.207*** (6.129)	0.150*** (3.592)	0.142*** (3.436)
N	300	300	300	300	300	300
R ²	0.373	0.456	0.582	0.594	0.601	0.613

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

Table 5. Endogeneity and robustness test results

Variables	Endogeneity test				Robustness test	
	(1)	(2)	(3)	(4)	(5)	(6)
DEI		0.199** (2.550)		0.294*** (9.280)	0.489*** (6.050)	0.423*** (12.640)
IV1	0.099*** (7.480)					
IV2			0.938*** (78.510)			
TIL	−0.020* (−1.890)	0.024*** (3.640)	0.000 (0.130)	0.036*** (5.820)	−0.094*** (−5.735)	0.024*** (3.511)
AML	−0.062*** (−7.740)	0.009 (1.400)	−0.005** (−2.590)	0.017*** (3.460)	0.090*** (6.881)	0.032*** (5.830)
LUI	−0.831*** (−2.670)	−0.527** (−2.350)	−0.117* (−1.870)	−0.193 (−1.230)	−0.082 (−0.191)	−0.203 (−0.439)
RHC	0.000 (−0.070)	0.007** (2.010)	−0.001 (−0.520)	0.005 (1.610)	−0.002 (−0.246)	0.010*** (2.870)
FDL	0.089*** (4.170)	−0.002 (−0.140)	0.010** (2.420)	−0.042*** (−3.930)	−0.000 (−0.016)	−0.040*** (−3.448)
CONSTANT	−0.663*** (−6.820)	0.118*** (2.670)	0.025 (1.540)	0.160*** (4.010)	0.889*** (8.131)	0.108** (2.172)
Under-identification test	48.091 ***		258.952 ***			
Weak identification test	55.935		6164.319			
R ²	0.584		0.597		300	260
N	300		270		0.449	0.660

Note: Values in parentheses are t-values. ***, **, and * denote significance levels at 1%, 5%, and 10%, respectively. IV diagnostics include the under-identification test (confirming model identification, $p < 0.1$), weak identification test (exceeding the Stock-Yogo threshold of 16.380).

To further assess robustness, two additional tests are conducted. The results of these tests are presented in columns (5)–(6) of Table 5. In column (5), we replace URI with the urban-rural coordination index developed by Zhang (2023). The coefficient of DEI is 0.489, remaining significantly positive. Column (6) reports results after all variables are winsorized at the 1% level. The estimated coefficient for DEI is 0.423, which remains positive and statistically significant. Taken together, these robustness checks provide additional support for Hypothesis 1.

4.2. Results of mediation effect test

The baseline analysis confirms that the digital economy significantly promotes URI. Based on this finding, this section further explores the underlying transmission mechanism, and the relevant results are presented in Table 6.

Column (1) displays the baseline regression results, reaffirming the significant effect of the digital economy on URI. Columns (2) and (3) present the mediation test results for INU based on Eqs. (2)–(3). The estimates indicate that DEI significantly promotes INU, which in turn contributes to URI. The corresponding results for MAR in columns (4)–(5). We find that

Table 6. Results of mediation effect tests

Variables	(1) URI	(2) INU	(3) URI	(4) MAR	(5) URI
DEI	0.341*** (11.158)	0.190*** (6.971)	0.313*** (9.550)	2.365*** (5.116)	0.303*** (9.775)
INU			0.148** (2.271)		
MAR					0.016*** (4.287)
TIL	0.029*** (4.697)	−0.060*** (−10.817)	0.038*** (5.213)	1.365*** (14.630)	0.007 (0.890)
AML	0.018*** (3.598)	−0.013*** (−2.919)	0.020*** (3.954)	−0.386*** (−5.188)	0.024*** (4.787)
LUI	−0.227 (−1.402)	0.903*** (6.255)	−0.361** (−2.106)	6.343** (2.590)	−0.329** (−2.068)
RHC	0.007** (2.232)	0.001 (0.229)	0.007** (2.217)	0.042 (0.830)	0.007** (2.086)
FDL	−0.031*** (−2.954)	0.087*** (9.218)	−0.044*** (−3.696)	−0.464*** (−2.896)	−0.024** (−2.282)
CONSTANT	0.142*** (3.436)	0.736*** (19.968)	0.033 (0.528)	−6.317*** (−10.100)	0.244*** (5.224)
N	300	300	300	300	300
R ²	0.613	0.785	0.620	0.854	0.636
Sobel test		Z = 3.263, P = 0.001		Z = 2.164, P = 0.030	
Bootstrap test		Indirect effect/total effect = 0.028/0.341 = 8.211% 95%CI [0.0063, 0.0512]		Indirect effect/total effect = 0.038/0.341 = 11.144% 95%CI [0.0192, 0.0602]	

Note: The non-parametric percentile bootstrap method for correcting deviations was used here, with 5,000 repetitions. ***, **, and * respectively represent the significance levels of 1%, 5% and 10%.

DEI significantly enhances MAR, and this improvement further facilitates URI. To verify the robustness of these mediation effects, we conduct both Sobel and bootstrap tests. Sobel test results for INU and MAR are statistically significant. Consistently, the bootstrap test confirms the existence of significant mediation effects. Quantitatively, INU and MAR account for 8.211% and 11.144% of the total effect, respectively. Overall, these findings suggest that industrial upgrading and marketization serve as important channels through which the digital economy promotes URI, providing empirical support for Hypotheses 2–3.

4.3. Results of moderation effect test

This study tested the moderating effects of Fiscal Support for Agriculture (FSA) and Urbanization (URB) using Eq. (4), with results shown in Table 7. In column (1), the coefficient of the interaction term DEI*FSA is 0.042, which is significant. This indicates that fiscal support for agriculture strengthens the positive effect of the digital economy on URI. Column (2) presents the results using URB. The interaction term DEI*URB is -0.043 , which is significant. This suggests that higher levels of urbanization dampen the integration-promoting effect of the digital economy. Taken together, these results provide empirical support for Hypotheses 4–5.

Table 7. Results of moderating effect tests

Variables	(1)	(2)
	FSA	URB
DEI	0.393*** (13.470)	0.345*** (11.837)
FSA	$-0.004^{***} (-2.534)$	
DEI * FSA	0.042*** (6.981)	
URB		$-0.043 (-0.827)$
DEI * URB		$-1.120^{***} (-7.047)$
TIL	0.016** (2.414)	0.026*** (4.332)
AML	0.023*** (4.415)	0.013** (2.375)
LUI	$-0.205 (-1.382)$	$-0.136 (-0.870)$
RHC	0.008*** (2.629)	0.008** (2.468)
FDL	$-0.025^{**} (-2.528)$	$-0.022^{**} (-2.224)$
CONSTANT	0.346*** (6.919)	0.273*** (6.635)
N	300	300
R ²	0.823	0.821

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

4.4. Results of threshold effects

To further capture potential nonlinearities, we apply the panel threshold regression model specified in Eq. (5). By conducting 300 bootstrap replications, we obtain the corresponding F statistic, p-value, and critical values, with the results reported in Tables 8–9. As shown in Table 8, the tests with single threshold and double thresholds are statistically significant, while the test with triple thresholds is not. Accordingly, the double-threshold model is selected,

with estimated threshold values of 0.397 and 0.482. In Table 9, when DEI is below 0.397, the coefficient of DEI is 0.163, which is statistically significant; when DEI lies between 0.397 and 0.482, the coefficient remains positive but is slightly weakened; and when DEI exceeds 0.482, the coefficient turns statistically insignificant. These findings indicate that the integration-promoting effect of the digital economy is strongest at early and intermediate stages, but exhibits diminishing marginal returns beyond a critical level of development. Taken together, these findings reveal a clear stage-dependent and nonlinear relationship between digital economy and URI, thereby supporting Hypothesis 6.

Table 8. Threshold effect tests for digital economy

Threshold Variable	Threshold number	Threshold value	F statistic	p-value	Critical value		
					10%	5%	1%
DEI	Single	0.397	57.850	0.000	15.575	20.690	27.288
	Double	0.482	22.060	0.010	12.643	15.273	20.382
	Triple	0.543	14.620	0.497	56.240	66.818	88.060

Table 9. Threshold regression results

Variables	Coef.	Std. Err.	t	p-value	95% Conf. Interval	
TIL	0.037***	0.009	4.040	0.000	0.019	0.055
AML	0.027**	0.013	2.040	0.042	0.001	0.052
LUI	-0.621	0.394	-1.570	0.117	-1.397	0.156
RHC	0.002	0.002	0.880	0.382	-0.002	0.006
FDL	0.083***	0.013	6.500	0.000	0.058	0.108
DEI ≤ 0.397	0.163***	0.042	3.890	0.000	0.080	0.245
0.397 < DEI ≤ 0.482	0.104**	0.040	2.610	0.010	0.026	0.183
DEI > 0.482	0.038	0.039	0.960	0.335	-0.040	0.116
CONSTANT	-0.757***	0.166	-4.570	0.000	-1.083	-0.431

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

5. Further discussion

5.1. How does digital economy promote URI in different dimensions?

Table 10 reports the estimation results of the four sub-dimensions of URI based on Eq. (1). The estimated coefficients for DEI are 0.361, 0.543, 0.138, and 0.203, respectively, with significance at the 1% level. Among the four dimensions, the effect is most pronounced in URSI, followed by UREI, URCI, and URPI. The stronger impacts on social, economic, and ecological integration are likely driven by advancements in digital public services, market integration, and environmental monitoring. Conversely, the relatively weaker impact on spatial integration (URPI) highlights that while digitalization can bridge virtual distances, it remains constrained by physical geographical barriers and infrastructure limitations (Su, 2022).

Table 10. Results of single-dimension test of URI

Variables	(1)	(2)	(3)	(4)
	UREI	URSI	URPI	URCI
DEI	0.361*** (5.669)	0.543*** (10.891)	0.138*** (2.999)	0.203*** (3.796)
TIL	0.027** (2.082)	0.002 (0.240)	0.065*** (7.020)	0.012 (1.156)
AML	0.007 (0.659)	0.060*** (7.459)	0.040*** (5.422)	-0.042*** (-4.857)
LUI	-0.342 (-1.013)	-0.483* (-1.830)	1.575*** (6.446)	-1.544*** (-5.461)
RHC	0.011 (1.558)	-0.004 (-0.741)	0.004 (0.856)	0.016*** (2.774)
FDL	-0.069*** (-3.121)	-0.054*** (-3.140)	-0.030* (-1.893)	0.039** (2.084)
CONSTANT	0.378*** (4.383)	0.472*** (6.997)	-0.655*** (-10.499)	0.311*** (4.300)
N	300	300	300	300
R ²	0.156	0.570	0.710	0.351

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

5.2. Which regions have benefited more from digital economy-driven urban rural integration?

Given the substantial regional disparities in both digital economy and URI, we divided the sample into eastern, central, and western regions. Table 11 presents the regression results. The estimated coefficients for DEI are 0.210, 0.285, and 0.261 respectively, all statistically significant. Notably, the estimated results show that the effect of the digital economy in promoting regional integration is significantly stronger in the central and western regions compared to the eastern. This pattern suggests that regions at intermediate stages of development are better positioned to capture the integration dividends of digital transformation. In contrast, the eastern region, which already exhibits relatively high levels of digitalization, which results in a comparatively weaker effect on further integration.

6. Conclusions

This study employs panel data from 30 provinces in China from 2013 to 2022 to explore the role of the digital economy in promoting URI. We find that the digital economy exerts a significant positive impact on URI, and this conclusion remains valid even after addressing the endogeneity concerns and conducting robustness checks. Mechanism analysis identifies industrial upgrading and marketization as key transmission channels: by improving resource allocation efficiency and accelerating structural transformation, the digital economy strengthens the foundational conditions for URI. Regarding moderating factors, fiscal agricultural support

Table 11. Regression results by region

Variables	(1) Eastern	(2) Central	(3) Western
DEI	0.210*** (4.841)	0.285*** (5.439)	0.261*** (6.960)
TIL	−0.015 (−1.335)	0.013 (1.480)	0.022** (2.523)
AML	0.034*** (5.244)	0.018** (2.474)	−0.046*** (−4.040)
LUI	−0.110 (−0.645)	0.348 (0.256)	1.599 (1.272)
RHC	0.011** (2.258)	−0.003 (−0.495)	0.005 (1.454)
FDL	0.009 (0.496)	0.033* (1.824)	0.034** (2.620)
CONSTANT	0.401*** (6.959)	0.011 (0.085)	0.300*** (5.312)
N	110	80	110
R ²	0.627	0.844	0.831

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

amplifies the positive effect, whereas the process of urbanization somewhat mitigates this effect. Furthermore, the threshold model analysis reveals a nonlinear relationship between the digital economy and URI: its contribution to URI is most pronounced in the early and intermediate stages, but weakens once a certain threshold is exceeded. Finally, we find that the digital economy exerts the greatest influence on social integration, with this effect being more prominent in central and western China.

Based on the empirical findings, we put forward the following policy recommendations. First, given the significant role of the digital economy in promoting URI, policymakers should prioritize advancing the digital economy to fully exploit its potential in boosting URI. Second, efforts should focus on industrial upgrading and deepening market-oriented reforms – specifically, strengthening digital empowerment for rural industries and nurturing new digital business models to enhance the transmission efficiency of the digital economy. Third, it is crucial to maintain fiscal support for agriculture and guide the urbanization process in a coordinated manner. The government should expand financial support for rural digital infrastructure construction projects, ensure fairness and transparency in fund allocation and foster effective synergy between urbanization and digital development. This will help improve rural living conditions and prevent rural marginalization amid urban expansion. Fourth, given the stage-dependent nature of digital development, policy priorities should gradually shift from scale expansion toward innovation-driven and inclusive digital transformation, with a focus on narrowing regional digital divides. Finally, digital technology should be more deeply integrated into public services, education, healthcare, and social security to promote equal access to opportunities between urban and rural residents. In particular, greater policy and resource support should be tilted toward underdeveloped rural regions.

This study has several limitations. Firstly, data constraints may compromise the national representativeness of some regions and obscure local-level disparities. Secondly, although this study reveals the different levels of URI, it does not explore how they interact with each other. Thirdly, the focus on China limits the generalizability of findings to contexts with different institutional arrangements. Future research can build on this work to address these limitations. For one, future research can use micro-level data to capture the digital behavior of households and companies or use spatial econometric models to investigate the mutual influence effects between different regions. For another, structural models may be constructed to better elucidate the complex interrelationships among the multiple dimensions of URI. Finally, we can add cross-country data to research the role of the global digital economy on sustainable urban-rural development.

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Author contributions

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Disclosure statement

The authors declare no conflict of interest.

Data availability

Data and code are available upon request.

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APPENDIX

Appendix A. Entropy weighting method calculation procedure

This Appendix outlines the computational steps for the entropy weighting method used to assess both URI and digital economy development. The method comprises three steps: standardization, entropy-based weight calculation, and composite index construction.

Based on their relationship with the evaluation objective, indicators are categorized as either positive or negative. All indicators are normalized via the min-max method to ensure comparability, as follows:

positive indicators:

$$Z_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}, \quad (1)$$

negative indicators

$$Z_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}. \quad (2)$$

In Eqs. (1)–(2), Z_{ij} is the normalized value of indicator j in region i , with $0 < Z_{ij} < 1$. $\max(X_j)$ and $\min(X_j)$ represent the maximum and minimum values of indicator j across all regions, respectively.

Then, the entropy value and corresponding weight of each indicator are calculated as follows:

Entropy value for indicator j :

$$e_j = -k \sum_{i=1}^m p_{ij} \times \ln(p_{ij}), \text{ where } k = \frac{1}{\ln(m)}, p_{ij} = \frac{Z_{ij}}{\sum_{i=1}^m Z_{ij}}. \quad (3)$$

Weight of indicator j :

$$W_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)}. \quad (4)$$

In Eqs (3)–(4), m is the number of regions, n is the number of indicators.

The overall score for region i is calculated as a weighted sum of the normalized indicators:

$$Score_i = \sum_{j=1}^n (W_j \times Z_{ij}). \quad (5)$$

This composite index represents the overall level of either URI or digital economy development. Higher values represent more favorable development outcomes.

Appendix B. Stationarity and multicollinearity tests

Table B1. Panel unit root tests

Symbol	LLC test	Fisher-ADF	Stationarity
URI	−14.542***	−11.332***	Stable
UREI	−7.821***	−7.207***	Stable
URSI	−26.854***	−8.753***	Stable
URPI	−17.723***	−12.181***	Stable
URCI	−8.987***	−8.641***	Stable
DEI	−5.552***	−10.820***	Stable
INU	−8.331***	−2.497***	Stable
MAR	−6.434***	−7.850***	Stable
FSA	−8.391***	−8.025***	Stable
URB	−6.543***	−6.561***	Stable
TIL	−1.855**	−2.416***	Stable
AML	−3.133***	−7.550***	Stable
LUI	−6.490***	−4.838***	Stable
RHC	−12.347***	−10.903***	Stable
FDL	−16.623***	−14.400***	Stable

Note: *, **, and *** represent the 10%, 5%, and 1% significance levels, respectively.

Table B2. Variance inflation factor (VIF) test

Variable	VIF	1/VIF
DEI	2.040	0.491
TIL	3.690	0.270
AML	2.080	0.481
LUI	3.830	0.261
RHC	1.010	0.989
FDL	2.260	0.443
Mean VIF	2.480	