frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 11 September 2025
DOI 10.3389/fsufs.2025.1642097

OPEN ACCESS

EDITED BY
Jianxu Liu,
Shandong University of Finance and Economics, China

REVIEWED BY
Cidonea Deponti,
Universidade de Santa Cruz do Sul, Brazil
Zhaoyang Lu,
Southwest University of Political Science and Law, China

*CORRESPONDENCE
Tingting Zhu
✉ zhutingting@ahut.edu.cn

RECEIVED 06 June 2025
ACCEPTED 27 August 2025
PUBLISHED 11 September 2025

CITATION
Jia X and Zhu T (2025) Rural digital economy drives rural industrial development through quality, efficiency, and dynamism transformations in China.
Front. Sustain. Food Syst. 9:1642097.
doi: 10.3389/fsufs.2025.1642097

Rural digital economy drives rural industrial development through quality, efficiency, and dynamism transformations in China

Xingmei Jia and Tingting Zhu*

School of Business, Anhui University of Technology, Ma'anshan, China

As networking, informatization, and digitization become increasingly embedded in agriculture and rural economies, the digital economy is emerging as a key driver of rural industrial development. Drawing on data spanning from 2013 to 2023, this study employs an entropy-weighted methodology to quantify the levels of rural digital economy and rural industrial development. Through mediation and moderation effect models, the research explores the mechanisms by which quality, efficiency, and dynamism transformations mediate the role of the rural digital economy in driving rural industrial development. The findings indicate a significant positive impact of rural digital economy on rural industrial development, with the magnitude of influence diminishing sequentially from China's central to western and eastern regions. Further analysis identifies quality, efficiency, and dynamism transformations as mediators, among which efficiency transformation exhibits the most pronounced mediating effect. Regional comparisons reveal that quality and dynamism transformations' mediation effects diminish sequentially from western to central and then eastern regions, whereas efficiency transformation's mediating role decreases from eastern to western and central regions, respectively. Regarding moderation effects, quality transformation prominently moderates in the eastern region, while efficiency and dynamic transformations are notably influential in the central region. Thus, the eastern region has transitioned into a high-quality development phase driven primarily by efficiency transformation, whereas central and western regions remain in phases characterized by scale expansion. Consequently, eastern regions should prioritize enhancing quality and efficiency through technological innovation and industrial upgrading to achieve superior quality and greater efficiency. Meanwhile, central and western regions should emphasize the synergistic effects of efficiency and dynamism transformations by optimizing resource allocation, boosting productivity, and invigorating market vitality to foster sustainable rural industrial development.

KEYWORDS

rural digital economy, rural industrial development, quality transformation, efficiency transformation, dynamism transformation

1 Introduction

The global pursuit of sustainable, inclusive, and technologically advanced growth has brought the digital economy to the forefront of economic transformation (Lu et al., 2025). Characterized by pervasive data integration, intelligent systems, and hyper connectivity, digitization has revolutionized industrial development, albeit unevenly. While cities have typically led this charge, the digital transformation of rural economies is emerging as a vital frontier, with international initiatives—from the EU's "Smart Villages" to India's Digital Agriculture Mission—highlighting its growing strategic importance (Li et al., 2025).

China presents a particularly illuminating context for exploring rural digital transformation. With vast regional disparities and a policy-driven agenda for rural revitalization, it offers both a testbed and a bellwether for digital integration in agricultural and peripheral industrial contexts. Since the 18th National Congress of the Communist Party, China's developmental emphasis has shifted from sheer speed to structural quality. At the heart of this shift is a digitally enabled reconfiguration of rural industries, raising key questions about how digital technologies alter not only what is produced, but how and by whom—and what this means for long-term rural resilience.

Although previous studies have examined components of this transition—ranging from digital infrastructure to rural e-commerce—systematic analysis of the mechanisms linking digital transformation with rural industrial development remains underdeveloped (Cong and Zhang, 2022). Specifically, how digitalization drives improvements in industrial quality, efficiency, and dynamism remains under-theorized and empirically fragmented. Addressing this gap requires a framework that not only captures these three dimensions but also traces their interrelations in the context of rural development.

This study adopts a quantitative, multi-dimensional approach to investigate how the rural digital economy influences transformations in quality, efficiency, and dynamism within rural industries, and how these transformations, in turn, contribute to rural industrial development. Drawing on longitudinal data from 2013 to 2022, we develop entropy-weighted indices to assess levels of rural digital economy and rural industrial development. Mediation and moderation effect models are employed to uncover the mechanisms underpinning these relationships and to identify the conditions under which digital transformation exerts the greatest developmental impact.

Our work builds on but moves beyond existing literature by integrating quality, efficiency, and dynamism into a unified framework to comprehensively understand rural industrial development driven by the rural digital economy. It advances knowledge by empirically examining how the rural digital economy moderates these transformations, clarifying their interplay. Furthermore, by employing multidimensional quantitative metrics, the study enriches qualitative insights and strengthens empirical robustness regarding fundamental economic transformations.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature and develops the research hypotheses, detailing the mechanisms through which the rural digital economy influences transformations in the quality, efficiency, and dynamism of rural industrial development. Section 3 outlines the methodological framework, including model construction, variable definitions, and data sources. Section 4 presents the empirical findings, encompassing baseline regression results, endogeneity and robustness checks, and a detailed mechanism analysis. Section 5 discusses the main findings, highlights theoretical and practical implications, and addresses limitations alongside avenues for future research. Section 6 concludes the paper.

2 Literature review and research hypotheses

2.1 Literature review

The digital economy's role as a catalyst for rural industrial development is now a central theme in development studies. A substantial body of work confirms its positive effects on industrial innovation, human capital enhancement, and green technology adoption, often generating positive spillover effects that bridge urban–rural divides (Cong and Zhang, 2022; Su et al., 2024). Conceptually, this transformation is understood through the dual lenses of "industrial digitization"—the integration of digital technology into existing rural sectors—and "digital industrialization," the emergence of new data-driven industries (Yan and Cao, 2024; Liu et al., 2024; Shu and Wang, 2024). The overarching consensus is that this digital infusion is critical for extending agricultural value chains, cultivating rural multifunctionality, and nurturing new enterprises (Wang and Ran, 2022).

Reflecting the field's maturation, the methods for measuring these phenomena have evolved significantly. Initial assessments focused on foundational elements like digital infrastructure and internet penetration rates (Mu and Ma, 2021). However, recent scholarship argues that such metrics are insufficient, leading to the development of comprehensive, multi-dimensional indices. These newer frameworks now integrate a wider array of indicators, capturing the nuances of the rural digital ecosystem, including digital financial inclusion, data resources, the digital transformation of rural life, and governance capacity (Zhang et al., 2023; Wu et al., 2022; Jiang et al., 2019; Qin et al., 2023; Shao et al., 2023). Concurrently, research has clarified the primary mechanisms through which the digital economy exerts its influence. Beyond simply reducing transaction costs, it has been shown to optimize the mobility of production factors, enhance agricultural efficiency via precision technologies, and expand market access through platform economies and rural e-commerce (Du and Lou, 2022; Eduard et al., 2020; Zhang, 2023a, 2023b).

Despite this progress, a critical gap remains in understanding the "qualitative nature" of the resulting industrial transformation. The literature predominantly evaluates development using composite index systems that aggregate diverse concepts such as industrial efficiency, structural upgrading, green growth, and sustainability (Qin et al., 2023; Tang and Sun, 2024; Liang, 2024). While valuable, these integrated approaches can mask the distinct, and sometimes competing, dynamics at play. For instance, a policy promoting transactional "efficiency" (e.g., optimizing logistics for bulk agricultural goods) may not inherently foster product "quality" (e.g., developing niche, high-value organic brands) or entrepreneurial "dynamism" (e.g., incubating innovative agritech start-ups). While some studies have referenced the concepts of quality, efficiency, and dynamism, they typically frame them as transmission channels or mediating effects (Zhang, 2023a, 2023b; Zhou and Zhou, 2021; Wang et al., 2024), rather than as distinct, interdependent dimensions of the developmental outcome itself. The fundamental question of how the rural digital economy simultaneously drives these separate transformations—and manages their potential trade-offs—remains underexplored.

To addresses this gap, we propose and test an analytical framework that disaggregates rural industrial development into three core, measurable outcomes: quality upgrading, efficiency improvement, and dynamic innovation. By analyzing these dimensions as distinct yet interconnected phenomena, we move beyond confirming the digital economy's overall positive effect. Instead, we aim to provide a more granular understanding of how digitalization specifically reshapes rural industries, offering crucial insights for designing more targeted and effective rural revitalization policies.

2.2 Research hypotheses

The digital economy is increasingly recognized as a transformative force in economic development, with profound implications for rural industrial upgrading. Its mechanisms can be systematically understood through three theoretical lenses. First, transaction cost economics and information asymmetry theory suggest that digital technologies reduce market frictions, enabling more efficient matching of supply and demand and fostering quality improvements (Akerlof, 1970; Coase, 1937; Williamson, 1985; Stigler, 1961). Second, theories of total factor productivity and resource allocation emphasize that digitalization enhances production efficiency by optimizing the use of inputs, integrating value chains, and reallocating resources toward more productive uses (Solow, 1957; Farrell, 1957; Hsieh and Klenow, 2009). Third, Schumpeterian innovation and endogenous growth perspectives highlight the role of innovation as a driver of long-term dynamism, with digital infrastructures catalyzing the emergence of new industries, business models, and institutional arrangements (Schumpeter, 1934; Romer, 1990; Aghion and Howitt, 1992).

Anchored in these theoretical traditions, this study posits that the rural digital economy reshapes industrial development through three distinct but interrelated mechanisms: quality transformation, efficiency transformation, and dynamism transformation. Accordingly, we derive the following hypotheses.

2.2.1 The mechanism of quality transformation

The pursuit of higher-quality growth reflects the tension between rising public demand for improved living standards and persistent structural inefficiencies. Transaction cost economics and information asymmetry theory hold that digital platforms reduce contracting costs and mitigate “lemons” problems by enhancing the credibility of information and signals of quality (Akerlof, 1970; Williamson, 1985; Spence, 1973). By integrating fragmented data flows, digital infrastructures lower information-gathering costs and enable accurate matching between supply and demand (Stigler, 1961). In parallel, the Porter hypothesis and ecological modernization theory suggest that digital and green infrastructure investments can simultaneously raise ecological performance and product quality, reinforcing competitiveness (Porter and van der Linde, 1995; Mol and Spaargaren, 2000). These processes foster clustering of specialized industries and strengthen branding and traceability in rural markets.

Quality transformation is a central dimension of agricultural modernization. It seeks to raise the quality and efficiency of production through technological, managerial, and institutional innovation, thereby shifting agriculture from traditional, extensive practices to refined, resource-efficient, and environmentally sustainable systems (Hu, 2023; Zhang et al., 2023). This transformation provides a crucial entry point for the digital economy to drive industrial upgrading by enhancing the standardization, branding, and sustainability of agricultural products. Through digital innovation and improved management, it enables enterprises to achieve both high-quality and rapid growth (Li and Li, 2024). In this way, quality transformation amplifies the enabling effects of digitalization, ensuring that technological progress translates into tangible gains in agricultural productivity and sustainability.

> *H1*: The rural digital economy enhances industrial upgrading by reducing information asymmetries and transaction costs, thereby promoting quality-oriented transformation in rural industries. In turn, improvements in quality reinforce the enabling role of digitalization, ensuring that technological advances translate into measurable gains in agricultural productivity and efficiency.

2.2.2 The mechanism of efficiency transformation

Efficiency transformation is central to sustaining high-quality economic growth and can be explained through productivity and resource allocation theories. Digital technologies enhance total factor productivity by improving complementarities among inputs, accelerating learning-by-doing, and enabling scale economies (Solow, 1957; Arrow, 1962; Leibenstein, 1966; Brynjolfsson and Hitt, 2003). They also improve allocative efficiency by reducing misallocation of capital and labor across firms, thereby raising aggregate productivity (Farrell, 1957; Hsieh and Klenow, 2009). In addition, digital coordination strengthens value-chain integration, lowering transaction costs across production, processing, distribution, and sales (Gereffi et al., 2005). Collectively, these mechanisms accelerate rural industrial efficiency transformation and enhance competitiveness.

Efficiency transformation amplifies the enabling role of the digital economy in traditional industries by optimizing factor allocation, innovating production methods, and enhancing managerial performance (Wang, 2022). While the digital economy provides abundant data and powerful computational capacity, translating these into timely and precise resource allocation remains challenging. Efficiency gains address this gap by improving the distribution of production factors, thereby accelerating digitalization and advancing industrial upgrading (Zhang et al., 2023). In agriculture, efficiency transformation combines with digital technologies to drive the adoption of intelligent machinery, IoT devices, and optimized supply-chain systems. These advances enable precision in sowing, fertilization, pesticide application, and automated harvesting, reducing labour dependence and material waste while lowering unit production costs (Li and Li, 2024). Beyond production, efficiency transformation underpins the reliable operation of emerging business models, delivering better user experiences and higher product quality. In turn, this raises value-added potential and supports the high-quality development of rural industries, facilitating their integration across primary, secondary, and tertiary sectors.

> *H2*: The rural digital economy improves industrial productivity by optimizing factor allocation and strengthening value-chain integration, thereby accelerating efficiency transformation in rural industries. In turn, efficiency gains amplify the enabling role of digitalization, ensuring that technological advances translate into measurable improvements in agricultural quality and efficiency.

2.2.3 The mechanism of dynamism transformation

Beyond quality and efficiency, long-term development requires cultivating new sources of growth. Schumpeterian innovation theory and endogenous growth models highlight the role of technological change and entrepreneurship in generating industrial dynamism (Schumpeter, 1934; Romer, 1990; Aghion and Howitt, 1992). Digital infrastructures foster such dynamism by creating conditions for novel industries, organizational forms, and business models, often aligned with local resource endowments (Ohlin, 1933; Lin, 2012). Theories of industrial clustering and local multipliers further suggest that new digital-enabled industries can induce knowledge spillovers, strengthen upstream–downstream linkages, and generate multiplier effects that sustain regional growth (Marshall, 1890; Porter, 1998; Moretti, 2010). These dynamics expand income opportunities, attract investment, and embed innovation as a central driver of rural transformation.

Dynamic transformation acts both as an engine and a catalyst in advancing rural industries within the digital economy. By introducing new infrastructure, production factors, and business models, it strengthens the enabling role of digitalization and accelerates transformation efficiency, becoming a powerful driver of rural industrial upgrading (Wang, 2022). Emerging from the latest wave of technological and industrial change, the digital economy exemplifies innovation-driven development. Harnessing technological innovation as its core momentum, it represents a critical pathway for achieving high-quality economic growth (Zhang et al., 2023).

> *H3*: The rural digital economy stimulates innovation-driven growth by fostering new industries, business models, and institutional arrangements, thereby advancing dynamism transformation in rural industries. In turn, this transformation amplifies the enabling role of digitalization, ensuring that technological progress delivers tangible improvements in agricultural quality and efficiency.

To illustrate this theoretical framework, Figure 1 synthesizes the mechanisms through which the rural digital economy influences rural industrial development. Anchored in established theories of transaction costs, productivity, and innovation, the model highlights how digital technologies foster industrial upgrading via three distinct but complementary transformations: quality, efficiency, and dynamism. These mechanisms are not independent; rather, they interact to form a reinforcing cycle that underpins the high-quality, innovation-driven development of rural industries. The digital economy reshapes rural industrial development through three interrelated mechanisms: (1) quality transformation, grounded in transaction cost economics and information asymmetry theory, whereby digital platforms reduce market frictions and enhance credible quality signaling; (2) efficiency transformation, informed by theories of total factor productivity and allocative efficiency, through which digitalization optimizes factor allocation and strengthens value-chain integration; and (3) dynamism transformation, underpinned by Schumpeterian innovation and endogenous growth theories, whereby digital infrastructures stimulate new industries, clusters, and multiplier effects. Together, these mechanisms form a systematic theoretical model of how digitalization catalyzes the upgrading of rural industrial structures.

3 Model construction and variable interpretation

3.1 Model construction

The traditional model establishes only the statistical significance of the association between X and Y, but it does not illuminate the underlying pathway. By contrast, the mediation model addresses this limitation: it not only tests whether X influences Y, but also reveals the mechanism of this influence. Specifically, it identifies the mediator M in the causal chain X → M → Y, thereby clarifying how X exerts its effect on Y and reducing the risk of mistaking an indirect pathway for a direct effect. To investigate the role of the three transformations-quality, efficiency, and dynamism—in the relationship between the rural digital economy and rural industrial development, we employ a mediation effect model composed of the following specifications:

$$Y_{it} = \alpha_0 + \alpha_1 D_{it} + \beta_j X_{it} + \varepsilon_{i,t} \tag{1}$$

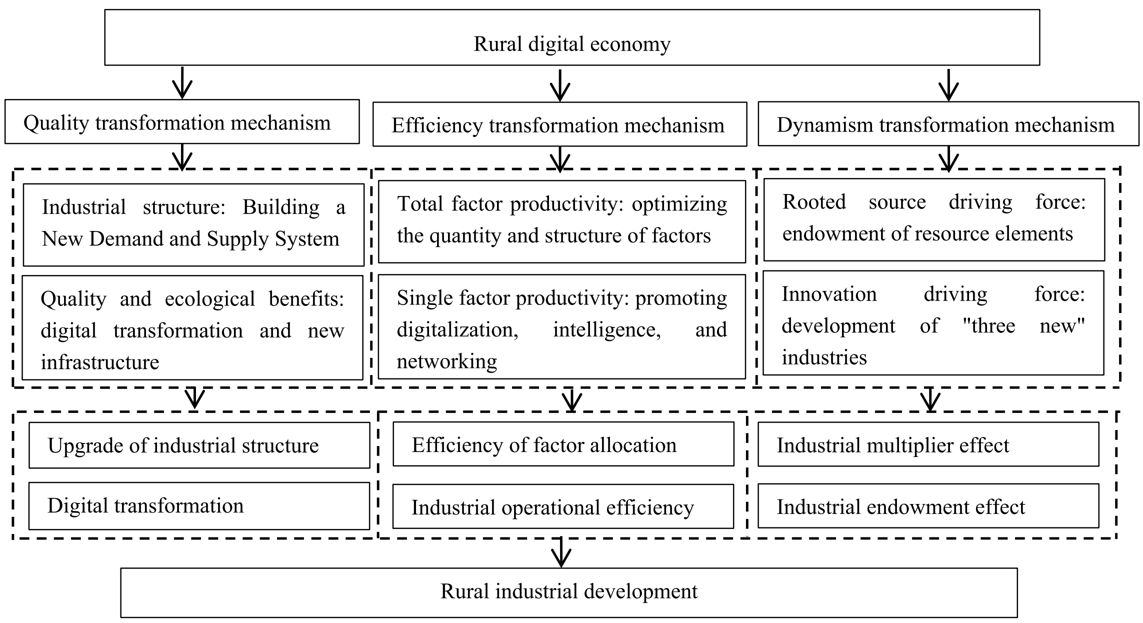

FIGURE 1
Conceptual framework of the mechanisms linking the rural digital economy and rural industrial development.

$$M_{it} = \alpha_0 + \alpha_1 D_{it} + \beta_j X_{it} + \varepsilon_{i,t} \quad (2)$$

$$Y_{it} = \alpha_0 + \alpha_1 D_{it} + \phi_1 M_{it} + \beta_j X_{it} + \varepsilon_{i,t} \quad (3)$$

Model (1) tests the baseline relationship between the rural digital economy and rural industrial development. Model (2) examines the impact of the rural digital economy on the three transformations. Model (3) includes both the rural digital economy and the transformations as explanatory variables to assess whether they jointly influence rural industrial development. Together, these models form the analytical structure of the mediation effect framework.

Here, Y_{it} represents the level of rural industrial development for province t in year i; D_{it} denotes the digital economy index; M_{it} refers to the levels of quality, efficiency, and dynamism transformation; X_{it} is a vector of control variables; and ε_{it} is the random error term.

The moderation model goes beyond clarifying how X influences Y; it examines the conditions under which this relationship strengthens, weakens, or even reverses. In doing so, it helps to delineate the boundary conditions of the effect. By incorporating interaction terms, the moderation model captures these conditional relationships with greater precision. To further examine whether the transformations moderate the relationship between the rural digital economy and rural industrial development, we introduce interaction terms between the rural digital economy and each transformation, leading to the following moderation model:

$$Y_{it} = \alpha_0 + \lambda_1 D_{it} + \lambda_2 M_{it} + \lambda_3 D_{it} \times M_{it} + \beta_j X_{it} + \varepsilon_{i,t} \quad (4)$$

3.2 Variable definitions and explanations

3.2.1 Core explanatory variables

From the perspective of economic statistics, many institutions, facing the inherent challenges of measurement and data collection, have primarily focused on the economic returns generated directly by digital technologies. These efforts are typically confined to the information industry or the information and communications technology (ICT) sector. In 2014, the Organization for Economic Co-operation and Development (OECD) emphasized that, beyond commercial and market performance, the evaluation of the digital economy should also account for societal impacts and intelligent infrastructure. In 2018, the US Bureau of Economic Analysis defined the digital economy in terms of digital infrastructure, digital transactions, user-generated content, and access to digital content, with digital infrastructure inherently dependent on computer network applications. That same year, the OECD further classified the digital economy into three domains: digitally enabled industries, digital platform intermediaries, and e-commerce, thereby encapsulating the notion of digital industrialization.

In China, the National Bureau of Statistics primarily concentrates on digital industrialization, with additional attention to the digital transformation of traditional sectors. Core components of the digital economy—such as the manufacturing of digital products, provision of digital services, application of digital technologies, and deployment of digital production factors—are categorized under digital industrialization. In contrast, efficiency gains arising from the integration of digital technologies into traditional industries fall under industrial digitalization. Drawing upon the conceptual framework of rural digital economy development and its defining characteristics, and following the methodologies proposed by prior study (Li and Zhang, 2017; Wu et al., 2022; Tian et al., 2023; Mu and Ma, 2021; Zhang and Bai, 2022; Lang et al., 2025; Neeraj et al., 2023; Yu et al., 2022), this study divides the development of the rural digital economy into three key components: rural digital infrastructure, digitalization of agriculture, and rural digital industrialization.

Rural digital infrastructure forms the cornerstone of the functioning and development of the rural digital economy, serving as a critical enabler of rural industrial growth. It encompasses foundational components such as telecommunications equipment, computer hardware, and software systems that support the operation and expansion of digital activities in rural regions (Mu and Ma, 2021; Wang et al., 2023). Assessing the extent of digital infrastructure penetration provides insight into the foundational readiness for digital economic development in these areas.

The level of industrial digitalization in rural areas reflects both the progress of the rural digital economy and the degree of digital integration within local industries. Rural industrial digitalization involves the effective incorporation of digital information technologies and digital tools into various stages of agricultural production, distribution, and operations (Tian et al., 2023; Yu et al., 2022). This integration facilitates the efficient use of agricultural resources, reduces production costs, improves environmental outcomes, enhances the quality of agricultural products, and lowers market transaction costs. As such, it plays a pivotal role in modernizing traditional agricultural practices and transforming modes of agricultural production. The evaluation of rural industrial digitalization in this study captures the extent to which digital technologies are applied in agricultural processes. It provides insight into production efficiency, product quality, and the long-term sustainability of rural industries (Wu et al., 2022).

Rural digital industrialization refers to the integration of digital technologies into rural industries to drive industrial upgrading and transformation. It serves as a key indicator for assessing the development and scale of digital industries in rural areas. Digital industrialization is characterized by the use of information as the core production input and digital technologies as the primary processing tool, aiming to generate knowledge-based products and extend their application across various sectors of society. In rural contexts, digital industries include telecommunications, software services, and internet-based information technology sectors. These industries process, structure, and analyze data to produce digital products and services (Zhang and Bai, 2022). The complete index system for the rural digital economy is presented in Table 1.

3.2.2 Core explained variable

In this study, rural industry refers to the broad spectrum of activities aimed at extending the boundaries of agriculture and fostering the integration of primary, secondary, and tertiary sectors within rural areas. Rooted in the county economy and supported by rural populations, farmland, and agricultural practices, rural industry develops through integrated models—such as agriculture allied with manufacturing or tourism—forming interconnected and mutually reinforcing sectors. These integrations are essential to advancing rural revitalization and the "three rurals" agenda (agriculture, rural areas,

TABLE 1 Indicator system for the rural digital economy.

Primary indicator	Secondary indicator	Indicator interpretation
Digital Infrastructure (0.3640)	Rural internet penetration rate (+) (0.0904)	Proportion of rural households with broadband access
	Rural smartphone penetration rate (+) (0.0907)	Number of mobile phones per 100 rural households
	Rural logistics infrastructure level (+) (0.0905)	Density of rural delivery routes
	Number of agricultural meteorological stations (+) (0.0924)	Total number of agricultural weather monitoring stations
Agricultural digitalization (0.3621)	Rural digital transactions (+) (0.0906)	Ratio of rural commodity market turnover to e-commerce transaction volume
	Agricultural production investment (+) (0.0904)	Fixed-asset investment in farming, forestry, animal husbandry and fisheries per unit area of cultivated land
	Level of agricultural mechanization (+) (0.0907)	Total power of agricultural machinery per unit of cultivated land
	Degree of agricultural electrification (+) (0.0904)	Ratio of value added in agriculture, forestry, animal husbandry and fisheries to total rural electricity consumption
Rural digital industrialization (0.2739)	Rural Digital Industrialization (+) (0.0909)	Digital Inclusive Finance Development Index for rural areas
	Agricultural and rural innovation hubs (+) (0.0920)	Number of digital agriculture innovation hubs (measured by number of Taobao Villages)
	Rural digital product and service consumption (+) (0.0910)	Share of per capita rural household expenditure on transport and communications

Values in parentheses denote the weights of each indicator.

and farmers). Given this conceptual framing, rural industrial development is fundamentally anchored in agricultural progress, with a strategic focus on achieving high-quality growth. Its advancement depends on the active participation of farmers, enterprises, and other stakeholders. Accordingly, the evaluation of rural industrial development must adopt a multidimensional approach, drawing on indicators that reflect diverse perspectives.

Although rural revitalization, industrial restructuring, integrated rural development, agricultural modernization, and high-quality agricultural growth have received considerable academic attention (Tian et al., 2022; Xin et al., 2021), comprehensive evaluation frameworks specifically targeting rural industrial development remain relatively scarce (Shen and Li, 2023; Zhang et al., 2021). In this study, the level of rural industrial development is assessed through three key dimensions: industrial output growth, value-added enhancement, and income generation.

1. Industrial output growth is evaluated using per capita yields of staple crops, oilseeds, and vegetables. These indicators serve as proxies for improvements in rural production and supply capacity. Higher per capita output reflects stronger agricultural productivity and, by extension, greater developmental potential (Tian et al., 2023).
2. Industrial value-added is measured by per capita gross output and per capita agricultural value-added in rural areas. These indicators capture production efficiency and reflect the value enhancement associated with rural industrialization (Jia, 2023). Generally, higher per capita value-added indicates stronger rural economic performance.
3. Industrial income generation is assessed via rural household per capita disposable income and per capita rural savings. These metrics reflect the contribution of rural industrial development to income growth among farmers and signal shifts in the broader economic wellbeing of rural populations (Wang et al., 2023). Higher per capita income typically correlates with improved rural economic conditions.

3.2.3 Mediating and moderating variables

Building on the theoretical framework and design principles of rural industrial development metrics, we propose a comprehensive indicator system to evaluate transformations in dynamism, efficiency, and quality. This system reflects the core dimensions of each transformation, grounded in the structural logic of rural economic transition.

The quality transformation is primarily assessed through changes in industrial structure, encompassing multiple dimensions such as industrial sophistication, rationalization, ecological integration, and diversification (Xu et al., 2018; Wang and Ren, 2019). The efficiency transformation is evaluated via total factor productivity, resource allocation efficiency, and single-factor productivity, capturing both the intensity and effectiveness of resource utilization (Wang and Ren, 2019; Chen and Chen, 2017). The dynamism transformation is reflected in indicators related to innovation-driven development—which underpins shifts in economic growth paradigms—and the composition and optimization of input factors, particularly the restructuring of production inputs (Zhao and Li, 2012; Xu et al., 2018). A detailed interpretation of these indicators is presented in Table 2.

For methodological selection, and following Li and Zhang (2017), we applied the entropy weight method to the above indicators, whereas other studies have employed the analytic hierarchy process (AHP), expert qualitative judgement, or the comprehensive index method (Shen and Wang, 2019). However, both AHP and expert judgement rely heavily on qualitative analysis and are susceptible to personal biases, which can compromise the robustness of results. By contrast, the entropy weight method derives weights from macro-level data and applies an objective weighting scheme, thereby minimizing subjective bias and enhancing scientific rigor.

The procedure comprises three steps. First, an evaluation matrix is constructed and standardized. Second, indicator weights are

TABLE 2 Evaluation framework for transformation in quality, efficiency, and dynamism.

Primary indicator	Secondary indicator	Tertiary indicator	Indicator interpretation
Dynamism transformation	Innovation-driven Momentum (0.5999)	Technological Innovation (+) (0.1998)	Ratio of total greenhouse agriculture area to arable land
		Patent Input (+) (0.2003)	Ratio of green agricultural product patents to total patents
		Knowledge Generation (+) (0.1998)	Index of agricultural intellectual property generation
	Rooted Momentum (0.4001)	Output Enhancement (+) (0.1997)	Per capita added value in agriculture, forestry, animal husbandry, and fisheries
		Consumption Upgrade (+) (0.2004)	Per capita rural consumption level
Efficiency transformation	Resource Allocation Efficiency (0.5013)	Change in Technical Efficiency (+) (0.1675)	Product of pure technical efficiency * scale efficiency
		Technological Progress Index (+) (0.1670)	DEA-Malmquist index
		Total Factor Productivity (+) (0.1668)	DEA-Malmquist index
	Single Factor Productivity (0.4987)	Capital Productivity (+) (0.1663)	Agricultural output per unit of capital input
		Labor Productivity (+) (0.1659)	Agricultural output per agricultural worker
		Land Productivity (+) (0.1665)	Agricultural output per unit of land input
Quality transformation	Industrial Structure (0.3757)	Rationalization Index (+) (0.1256)	Theil index
		Diversification Index (+) (0.1250)	Reciprocal of the Herfindahl index
		Industrial Agglomeration Index (+) (0.1251)	Location entropy index
	Socioeconomic Quality Benefits (0.3751)	Product Competitiveness Index (+) (0.1252)	Number of certified green agricultural products
		Employment Absorption Ratio (+) (0.1249)	Ratio of primary sector employment to total employment
		Tax Contribution Ratio (+) (0.1250)	Share of rural industrial tax revenue in national tax revenue
	Ecological Environment (0.2492)	Fertilizer Use (−) (0.1246)	Fertilizer use per unit area
		Pesticide Use (−) (0.1246)	Pesticide use per unit area

Values in parentheses denote the weights of each indicator.

derived using an information entropy approach. Finally, the weighted indicators and standardized matrix are combined to compute the composite order parameters of the rural digital economy, rural industrial development, and the three major transformations.

3.2.4 Control variables

The rural digital economy exerts a significant influence on the development of rural industries. However, other factors also play a critical role. These include the relative stagnation of agricultural institutions, the rigid constraints imposed by resource endowments, limited capacity for technological innovation, and the slow formation of industrial clusters. Such factors collectively shape the trajectory of agricultural development. Under the growing emphasis on sustainable agriculture, emerging forms such as organic and smart agriculture are gaining momentum. In this context, environmental protection and infrastructure—particularly farmland water conservancy—have become increasingly pivotal. To enhance robustness, we control for the financial environment, urbanization rate, trade openness, fiscal support for agriculture, and rural human capital. The key variables and their measurement approaches are summarized in Table 3. All variables are assessed using relative indicators to ensure greater data reliability and consistency.

3.3 Data sources

To ensure data availability and consistency in statistical standards, data from Tibet, Hong Kong, Macao, and Taiwan were excluded; the analysis thus covers 30 provinces (including municipalities and autonomous regions) in mainland China. Data on rural broadband subscriptions, mobile phone ownership per 100 rural households, rural postal routes, agricultural meteorological stations, e-commerce transaction volume, total agricultural machinery power, gross value added of agriculture, forestry, animal husbandry and fishery, rural household expenditure on transport and communications, rural per capita consumption expenditure, per capita output of grain, oil crops and vegetables, and per capita disposable income of rural households were sourced from the China Statistical Yearbook and the website of the National Bureau of Statistics. The Digital Inclusive Finance Index for rural areas was obtained from the Digital Finance Research Center at Peking University (2011–2023). The number of rural entrepreneurship and innovation bases—measured by the number of Taobao Villages in each province—was derived from the China Taobao Village Research Report published by the Ali Research Institute. Additional indicators were collected from the China Rural Statistical Yearbook, the China Urban–Rural Construction Statistical Yearbook, the EPS Global Statistics Database, and various provincial statistical

TABLE 3 Key variables and measurement methods.

Variable	Variable symbol	Measurement method
Rural industrial development	*Y*	Calculated based on a constructed indicator system
Rural digital economy	*D*	Calculated based on a constructed indicator system
Quality transformation	*QT*	Calculated based on a constructed indicator system
Efficiency transformation	*ET*	Calculated based on a constructed indicator system
Dynamism Transformation	*DT*	Calculated based on a constructed indicator system
Financial environment	*FE*	Ratio of loans to the agriculture, forestry, animal husbandry, and fishery sectors to total agriculture-related loans
Urbanization rate	*UR*	Ratio of urban population to total resident population
Trade openness	*TO*	Ratio of agricultural exports to total exports
Fiscal support for agriculture	*FS*	Ratio of fiscal expenditures on agriculture to total fiscal expenditures
Rural human capital	*HC*	Natural logarithm of average years of schooling among the rural population

yearbooks. Missing values were imputed using interpolation. Given regional differences in resources and location, certain inconsistencies in statistical definitions may persist at the provincial level; where necessary, data were refined to improve accuracy and comparability.

Data on greenhouse agriculture area were obtained from the China Agriculture Yearbook (2014–2024). The number of green agricultural product patents and certified green agricultural products were sourced from the China Center for Agricultural Data (CCAD) at Zhejiang University. The Agricultural Intellectual Property Creation Index was derived from the China Agricultural Intellectual Property Index Report. Additional data were gathered from the website of the National Bureau of Statistics and the China Statistical Yearbook (2014–2024); missing values were supplemented using the China Rural Statistical Yearbook and various provincial statistical yearbooks.

4 Empirical results and analysis

4.1 Baseline regression analysis

As reported in Table 4, the estimated coefficient linking the rural digital economy to rural industrial development is 0.628, significant at the 5% level. This result indicates a robust positive association between the two variables. To assess potential collinearity, we calculated the variance inflation factor (VIF). As shown in Table 5,

TABLE 4 Pearson correlation coefficients of core variables.

Variable	*Y*	*D*	*QT*	*ET*	*DT*
Y	1				
D	0.6278**	1			
QT	0.4909**	0.5689**	1		
ET	0.6869**	0.5306**	0.5235**	1	
DT	0.5644**	0.5335**	0.3421**	0.5166**	1

**$p < 0.01$.

all values fall well below the conventional threshold of 5, suggesting that multicollinearity is not a concern. Furthermore, stability diagnostics presented in Table 6 confirm that both the rural digital economy and rural industrial development exhibit consistent and stable effects within the model.

Building on the above analysis, we first estimate Equation 1 using panel data from 2013 to 2022. The results are presented in Column (1) of Table 7. The coefficient on rural digital economy is positive and statistically significant at the 1% level, indicating that digitalization significantly promotes the development of rural industries. This finding aligns with our initial hypothesis. As digital capabilities improve and mechanized production becomes more widespread, the demand for manual labor in agricultural production decreases, leading to the release of labor resources. Concurrently, the emergence of new forms of agriculture—such as facility-based and digital agriculture—requires a more skilled and technologically literate workforce, enhancing agricultural productivity. This reflects an improvement in capital efficiency driven by technological advancement, which in turn plays a crucial role in fostering rural industrial development.

4.2 Endogeneity test

Given the potential bidirectional causality between the rural digital economy and rural industrial development, we address endogeneity concerns by employing the village road paving rate as an instrumental variable. This variable satisfies the exclusion restriction, as it is unlikely to directly influence rural industrial development, while also fulfilling the relevance condition, being foundational to both digital infrastructure and industrial activity. Based on this specification, we apply GMM regression. As shown in Table 8, the tests indicate no endogeneity among the variables, supporting the reliability of the results.

4.3 Robustness checks

To evaluate the robustness of the relationship between the rural digital economy and rural industrial development, we employed three complementary strategies: subsample analysis, tail reduction, and replacement of the core explanatory variable. In the subsample analysis, the four centrally administered municipalities were excluded from the dataset. As reported in Table 9, the estimated coefficient for the rural digital economy remains significantly positive, aligning closely with the baseline results. This consistency strengthens confidence in the robustness of the main conclusion.

TABLE 5 Variance inflation factor (VIF) test results.

Variable	*D*	*QT*	*ET*	*DT*	*FE*	*UR*	*TO*	*FS*	*HC*
VIF	2.0603	1.7246	1.7447	1.7800	2.2283	3.7403	2.9009	2.3293	1.6284
1/VIF	0.4854	0.5798	0.5732	0.5618	0.4488	0.2674	0.3447	0.4293	0.6141

TABLE 6 Panel unit root test.

Variable	Rural industrial development			Rural digital economy		
	Statistic	*p*-value	Result	Statistic	P-value	Result
LLC	−5.8762	0.0000	Stable	−8.8759	0.0000	Stable
IPS W	−2.6709	0.0038	Stable	−4.0572	0.0000	Stable
ADF	97.4735	0.0016	Stable	118.005	0.0000	Stable
PP	178.748	0.0000	Stable	227.979	0.0000	Stable

TABLE 7 The Impact of the rural digital economy on rural industrial development.

Explained variable	Rural industrial development	
Intercept	0.0127 (0.2376)	−0.1024 (−0.8054)
Rural digital economy	0.9388** (7.7920)	0.8661** (6.4924)
Control variables	Not included	Included
R^2	0.3941	0.4225
Sample size	330	330
F-test (df)	F (1,328) = 60.7158	F (6,323) = 14.9820

Dependent variable is rural industrial development. *$p < 0.05$, **$p < 0.01$. t-values are reported in parentheses.

TABLE 8 Generalized method of moments (GMM) estimation results.

Variable	Unstandardized coefficient		t-value	p-value	R^2	Adjusted R^2	Wald χ^2
	Coefficient	Std. error					
Constant	−0.1987	0.2260	−0.8794	0.3792	0.3257	0.3132	$\chi^2(6) = 93.6530$, $p = 0.0000$
Rural digital economy	0.3540	1.0358	0.3417	0.7325			
Control variables	Included	Included					

*$p < 0.05$.

TABLE 9 Robustness checks.

Variable	Subsample analysis	Bidirectional tail reduction processing	Replace core explanatory variables
Constant	−0.0384 (−0.3146)	−0.1080 (−0.8521)	−0.2729 (−1.5115)
Rural digital economy	0.9489** (8.0903)	0.8956** (6.6541)	0.0094* (2.2893)
Control variables	Included	Included	Included
R^2	0.4549	0.4254	0.1677
Sample size	286	330	330
F-test (df)	F (6,279) = 24.7624	F (6,323) = 16.0458	F (6,323) = 4.7041

*$p < 0.05$, **$p < 0.01$.

4.4 Regional heterogeneity analysis

4.4.1 Regional heterogeneity test

To account for potential regional heterogeneity in the effect of the rural digital economy, we further conduct subsample regressions by region (eastern, central, and western China). As shown in Columns (2) to (4) of Table 10, the rural digital economy exerts a positive impact on rural industrial development across all three regions. This suggests that the positive effect of digitalization on rural industry is robust and not limited by geographical location. However, the

TABLE 10 The impact of the rural digital economy on rural industrial development.

Variable	Eastern China	Central China	Western China
Intercept	−0.0734 (−0.2377)	−0.6374* (−2.2349)	0.1081 (0.3537)
Rural digital economy	0.4316** (2.9515)	1.0222** (3.6008)	0.9581** (5.5406)
Control variables	Included	Included	Included
R^2	0.4894	0.5685	0.5345
Sample size	121	88	121
F-test (df)	F (6,114) = 29.4497	F (6,81) = 52.8585	F (6,114) = 27.4874

Dependent variable is rural industrial development. *p < 0.05, **p < 0.01. t-values are reported in parentheses.

TABLE 11 Quantile regression estimates.

Variable	Nationwide			Eastern China		
	Quantile 0.25	Quantile 0.50	Quantile 0.75	Quantile 0.25	Quantile 0.50	Quantile 0.75
Constant	−0.2174 (−1.9273)	−0.2444 (−1.8268)	0.0328 (0.2061)	−0.2203 (−0.7397)	−0.2341 (−0.7888)	−0.1277 (−0.4490)
Rural digital economy	0.7376** (11.0221)	0.8786** (9.6546)	0.9665** (8.5046)	0.3038** (3.6852)	0.5148** (5.0994)	0.4669** (3.1627)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	330	330	330	121	121	121
R^2	0.2219	0.2457	0.2895	0.2416	0.3254	0.3406

Variable	Central China			Western China		
	Quantile 0.25	Quantile 0.50	Quantile 0.75	Quantile 0.25	Quantile 0.50	Quantile 0.75
Constant	−0.7606* (−2.1712)	−0.7373* (−2.3456)	−0.4073 (−1.5876)	−0.1915 (−0.8841)	−0.2466 (−1.0429)	0.6180* (2.3674)
Rural digital economy	0.6130* (2.5433)	0.8965** (3.9217)	1.3350** (6.7430)	0.6981** (5.1326)	0.9807** (6.9617)	1.3916** (8.8987)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	88	88	88	121	121	121
R^2	0.3057	0.39	0.4486	0.3308	0.3248	0.3677

*p < 0.05, **p < 0.01.

magnitude of the effect varies considerably: it is strongest in the central region, followed by the western region, and weakest in the east. One possible explanation is that the eastern region, with its strong manufacturing and service sectors, has a relatively weak agricultural base. Although the rural digital economy in the east developed earlier, its applications have predominantly benefited non-agricultural sectors. In contrast, agriculture plays a more prominent role in the central region, where structural advantages and a favorable layout enhance agricultural competitiveness. Here, the rural digital economy has accelerated agricultural modernization, supporting the broader rural revitalization strategy. In the western region, despite natural constraints such as climate, the growth of specialized agriculture has been notable. The integration of digital technologies has enhanced precision in agricultural production, further propelling rural industrial development.

4.4.2 Regional quantile regression analysis

Quantile regression was employed to examine the effects of the rural digital economy across different points in the conditional distribution of rural industrial development in different regions. Unlike ordinary least squares regression, quantile regression does not require the assumption of normally distributed residuals, is robust to outliers, and addresses potential heteroscedasticity, thereby providing a more comprehensive assessment of the relationship between explanatory and response variables. To assess the stability of the effect, quantiles at the 0.25, 0.50, and 0.75 levels were selected. The results, presented in Table 11, test whether the impact of the rural digital economy on rural industrial development remains consistent across these distributional points.

Quantile regression results reveal that the rural digital economy exerts a consistently positive influence on rural industrial development. Moreover, this influence intensifies along higher quantiles. Specifically, at lower levels of rural industrial development, the rural digital economy's impact is relatively limited, whereas at higher development levels, the effect becomes markedly stronger. These findings underscore the robustness of the rural digital economy's role in fostering rural industry across varying development stages.

Regional heterogeneity is also evident. In the eastern China, the rural digital economy's impact coefficient increases from 0.3038 to

TABLE 12 Mediating effect of quality transformation.

Explained variable	Nationwide			Eastern China		
	Rural industrial development	Quality transformation	Rural industrial development	Rural industrial development	Quality transformation	Rural industrial development
Constant	−0.1024 (−1.0002)	0.1062 (1.0476)	−0.1250 (−1.2450)	−0.0734 (−0.2574)	−0.0645 (−0.1844)	−0.0716 (−0.2501)
Rural digital economy	0.8661** (12.4407)	0.7870** (11.4143)	0.6986** (8.6519)	0.4316** (4.4468)	0.8495** (7.1372)	0.4079** (3.4807)
Quality transformation			0.2128** (3.8695)			0.0279 (0.3637)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	330	330	330	121	121	121
R^2	0.4225	0.3609	0.4482	0.4894	0.4542	0.4900

Explained Variable	Central China			Western China		
	Rural industrial development	Rural digital economy	Rural industrial development	Rural industrial development	Quality transformation	Rural industrial development
Constant	−0.6374* (−2.2941)	−1.2549** (−5.4913)	−0.4208 (−1.2979)	0.1081 (0.5728)	0.1786 (1.0680)	0.0615 (0.3318)
Rural digital economy	1.0222** (5.0584)	0.5905** (3.5529)	0.9202** (4.2527)	0.9581** (8.5226)	0.5601** (5.6218)	0.8120** (6.5400)
Quality transformation			0.1726 (1.2830)			0.2609* (2.5264)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	88	88	88	121	121	121
R^2	0.5685	0.6224	0.5772	0.5345	0.3623	0.5594

*$p < 0.05$, **$p < 0.01$.

0.5148 as the quantile shifts from 0.25 to 0.5. However, at the 0.75 quantile, the coefficient declines to 0.4669, suggesting a potential saturation effect—where the marginal influence of the rural digital economy diminishes once rural industry reaches a certain development threshold.

In contrast, the central China exhibits a consistently positive and increasingly strong relationship across quantiles. The coefficient rises from 0.6130 at the 0.25 quantile to 0.8965 at 0.5, and further to 1.3350 at 0.75, indicating a sustained amplification of digital economic influence as rural industrial development advances.

A similar pattern emerges in the western China, where all estimated coefficients are positive and significant. As the quantile increases from 0.25 to 0.5 to 0.75, the coefficients climb from 0.6981 to 0.9807 and then to 1.3916, respectively. This progression suggests that the rural digital economy increasingly contributes to rural industrial advancement in less-developed western areas.

4.5 Mechanism analysis

To assess more rigorously the impact of the rural digital economy on the rural industrial development, we examined mediation and moderation effects through the lenses of quality, efficiency, and dynamism.

4.5.1 Analysis of quality transformation mechanism

To investigate how the rural digital economy influences rural industrial development via quality transformation, we conduct a mediation analysis based on Equations 1–3. The regression results are presented in Table 12.

National-level analysis reveals that the rural digital economy exerts a strong and statistically significant positive effect on rural industrial development ($\beta = 0.8661$, $p < 0.01$; Column 1). It also significantly enhances industrial quality transformation ($\beta = 7{,}870$, $p < 0.01$; Column 2). When both rural digital economy and quality transformation are included as explanatory variables (Column 3), the rural digital economy remains significant ($\beta = 0.6986$, $p < 0.01$), though the coefficient decreases, suggesting a mediating role of quality transformation. These findings support the hypothesis that the rural digital economy promotes rural industrial development primarily through improvements in industrial quality. This implies a transmission mechanism of: Rural Digital Economy → Quality Transformation → Rural Industrial Development.

Regional-level analysis further supports this mediation pathway, though the effect sizes and significance levels vary. In the eastern China, the rural digital economy significantly promotes both rural industrial development and quality transformation, with both relationships passing the 5% significance threshold. When both

TABLE 13 Moderating effect of quality transformation.

Variable	Nationwide	Eastern China	Central China	Western China
Constant	0.2377* (2.1967)	0.0733 (0.2644)	0.0513 (0.1431)	0.5147* (2.4164)
Rural digital economy	0.7324** (9.0615)	0.4518** (3.9986)	0.9726** (4.2220)	0.8283** (6.6224)
Quality Transformation	0.2169** (3.9840)	0.0526 (0.7124)	0.1710 (1.2667)	0.2548* (2.4641)
Rural digital economy * Quality Transformation	1.1528** (2.7877)	1.7437** (3.3476)	0.6909 (0.6801)	0.7538 (1.0487)
Control variables	Included	Included	Included	Included
Sample size	330	121	88	121
R^2	0.4612	0.5364	0.5797	0.5637

*$p < 0.05$, **$p < 0.01$.

variables are included simultaneously, the rural digital economy retains a positive effect on rural industrial development, suggesting that quality transformation acts as a mediating mechanism. The central China exhibits similar patterns, with the rural digital economy's impact on rural industrial development slightly exceeding that of the eastern region. Again, the coefficient declines when quality transformation is controlled for, reinforcing the mediating role of quality transformation. In the western China, the mediating effect of quality transformation is also evident, with the rural digital economy influencing rural industrial development primarily through improvements in industrial quality.

Based on Equation 4, the moderating effect of quality transformation is presented in Table 13. National-level analysis reveals that quality transformation moderates the relationship between the rural digital economy and rural industrial development. Among the three regions, this moderating effect is most pronounced in the eastern region, where the influence is both substantial and statistically significant. In contrast, the central and western regions exhibit weaker moderating effects, which do not reach conventional levels of statistical significance.

4.5.2 Analysis of efficiency transformation mechanism

Table 14 presents evidence that efficiency transformation plays a mediating role in the relationship between the rural digital economy and rural industrial development. Specifically, column (2) indicates that the rural digital economy significantly enhances efficiency transformation, with an effect coefficient of 0.7278, which passes the significance test. When both the rural digital economy and efficiency transformation are included as explanatory variables, the rural digital economy still exerts a significant positive impact on rural industrial development, although its coefficient declines compared to that in column (1). This suggests that the rural digital economy improves industrial efficiency and thereby advances rural industrial development. At the national level, this implies that the rural digital economy can foster rural industrial development via the pathway of efficiency transformation—that is, rural digital economy→efficiency transformation→rural industrial development.

A comparative analysis of the mediating effect across three regions reveals distinct patterns. In the eastern region, the rural digital economy significantly promotes efficiency transformation, which in turn contributes meaningfully to rural industrial development. This confirms the feasibility of the mediating pathway through efficiency transformation. In contrast, the central region exhibits a weaker mediating effect: while both the rural digital economy and efficiency transformation independently have significant positive effects on rural industrial development, the rural digital economy does not significantly enhance efficiency transformation. This indicates an absence of a strong mediating mechanism in this region. In the western region, however, the rural digital economy substantially promotes efficiency transformation, with an effect coefficient of 0.8497. When both factors are included as explanatory variables, they each have significant positive effects on rural industrial development, and the coefficient for the rural digital economy decreases. This pattern confirms a clear mediating role of efficiency transformation in the western region.

Based on Equation 4, as shown in Table 15, efficiency transformation serves as a moderator in the relationship between the rural digital economy and rural industrial development at the national level. The rural digital economy's impact on rural industrial development is conditioned by the level of efficiency transformation. When comparing across regions, the moderating effect is most pronounced in the central region, where the influence is strongest. The western region follows, while the eastern region exhibits a comparatively weaker moderating effect.

4.5.3 Analysis of dynamism transformation mechanism

Table 16 demonstrates that, at the national level, dynamism transformation acts as a mediating factor in the relationship between the rural digital economy and rural industrial development. Specifically, column (2) shows that the rural digital economy significantly enhances dynamism transformation, with an effect coefficient of 0.6454 that is statistically significant. When both the rural digital economy and dynamism transformation are included as explanatory variables, the rural digital economy continues to exert a significant positive impact on rural industrial development; however, its coefficient decreases relative to that in column (1). This indicates that the rural digital economy improves the driving forces of industrial development, thereby elevating the overall level of rural industrial development. In other words, at the national scale, the rural digital economy promotes rural industrial development in part through its effect on dynamism transformation—that is, rural digital economy→dynamism transformation→rural industrial development.

A comparative analysis across regions reveals notable heterogeneity in this mediating effect. In the eastern region, while the rural digital economy significantly fosters dynamism transformation, the mediating effect in the eastern region is weak. In contrast, in both the central and western regions, the rural digital

TABLE 14 Mediating effect of efficiency transformation.

Explained Variable	Nationwide			Eastern China		
	Rural industrial development	Efficiency transformation	Rural industrial development	Rural industrial development	Efficiency transformation	Rural industrial development
Constant	−0.1024 (−1.0002)	−0.2013 (−1.7100)	−0.0112 (−0.1271)	−0.0734 (−0.2574)	−0.5302 (−1.4966)	0.1100 (0.4210)
Rural digital economy	0.8661** (12.4407)	0.7278** (9.0879)	0.5364** (8.0437)	0.4316** (4.4468)	0.5638** (4.6776)	0.2365* (2.4611)
Efficiency transformation			0.4530** (10.9558)			0.3460** (5.0582)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	330	330	330	121	121	121
R^2	0.4225	0.3324	0.5793	0.4894	0.466	0.5837

Explained Variable	Central China			Western China		
	Rural industrial development	Efficiency transformation	Rural industrial development	Rural industrial development	Efficiency transformation	Rural industrial development
Constant	−0.6374* (−2.2941)	−1.2320** (−4.3275)	−0.0063 (−0.0240)	0.1081 (0.5728)	0.0563 (0.2551)	0.0853 (0.5108)
Rural digital economy	1.0222** (5.0584)	−0.0396 (−0.1911)	1.0425** (6.0217)	0.9581** (8.5226)	0.8497** (6.4658)	0.6137** (5.2792)
Efficiency transformation			0.5122** (5.5152)			0.4053** (5.7193)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	88	88	88	121	121	121
R^2	0.5685	0.5014	0.6874	0.5345	0.4402	0.639

$*p < 0.05$, $**p < 0.01$.

TABLE 15 Moderating effect of efficiency transformation.

Variable	Nationwide	Eastern China	Central China	Western China
Constant	0.3461** (3.6939)	0.1268 (0.4794)	0.6193* (2.1959)	0.4464* (2.4771)
Rural digital economy	0.5753** (8.8688)	0.2260* (2.4594)	1.1892** (7.0387)	0.7225** (6.4498)
Efficiency transformation	0.4189** (10.3412)	0.3094** (4.6716)	0.4724** (5.3485)	0.3405** (4.9932)
Rural digital economy * Efficiency Transformation	1.2619** (4.9409)	1.3355** (3.4256)	2.1553** (3.3332)	1.4522** (4.1097)
Control variables	Included	Included	Included	Included
Sample size	330	121	88	121
R^2	0.609	0.6232	0.7259	0.6863

$*p < 0.05$, $**p < 0.01$.

economy significantly promotes dynamism transformation. When both variables serve as predictors of rural industrial development, each exerts a significant positive effect, and the coefficient for the rural digital economy declines. These results confirm that dynamism transformation plays a clear mediating role in the central and western regions.

Based on Equation 4, as demonstrated in Table 17, dynamism transformation moderates the relationship between the rural digital economy and rural industrial development at the national level. Comparative analysis across regions reveals that the moderating effect is most pronounced in the central and eastern region, where the influence is strongest. In contrast, the western regions exhibit relatively weaker moderating effects, with only minor differences between them.

5 Discussion

5.1 Research findings

Using province-level data from 2013–2023, we construct indices of the rural digital economy and rural industrial development (entropy-weight method) and estimate mediation and moderation

TABLE 16 Mediating effect of dynamism transformation.

Explained variable	Nationwide			Eastern China		
	Rural industrial development	Dynamism transformation	Rural industrial development	Rural industrial development	Dynamism transformation	Rural industrial development
Constant	−0.1024 (−1.0002)	−0.0308 (−0.3071)	−0.0928 (−0.9503)	−0.0734 (−0.2574)	−0.4369 (−1.4686)	0.0075 (0.0264)
Rural digital economy	0.8661** (12.4407)	0.6454** (9.4617)	0.6661** (8.8720)	0.4316** (4.4468)	0.2927** (2.8924)	0.3774** (3.8081)
Dynamism Transformation			0.3099** (5.7182)			0.1853* (2.0929)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	330	330	330	121	121	121
R^2	0.4225	0.3797	0.4757	0.4894	0.4266	0.5085

Explained variable	Central China			Western China		
	Rural industrial development	Dynamism transformation	Rural industrial development	Rural industrial development	Dynamism transformation	Rural industrial development
Constant	−0.6374* (−2.2941)	−0.5078 (−1.7147)	−0.4956 (−1.8242)	0.1081 (0.5728)	0.1062 (0.6223)	0.0862 (0.4620)
Rural digital economy	1.0222** (5.0584)	0.5926** (2.7513)	0.8568** (4.2207)	0.9581** (8.5226)	0.9268** (9.1182)	0.7667** (5.2557)
Dynamism transformation			0.2791** (2.7874)			0.2066* (2.0206)
Control variables	Included	Included	Included	Included	Included	Included
Sample size	88	88	88	121	121	121
R^2	0.5685	0.3441	0.6067	0.5345	0.6197	0.5507

*$p < 0.05$, **$p < 0.01$.

TABLE 17 Moderating effect of dynamism transformation.

Variable	Nationwide	Eastern China	Central China	Western China
Constant	0.3027** (2.7991)	0.1512 (0.5292)	−0.1337 (−0.4672)	0.4786* (2.1682)
Rural digital economy	0.6746** (8.9868)	0.3560** (3.6911)	0.9476** (4.7751)	0.7877** (5.2894)
Dynamism Transformation	0.2883** (5.1803)	0.2037* (2.3641)	0.1782 (1.7210)	0.1733 (1.5479)
Rural digital economy * Dynamism Transformation	0.4514 (1.6387)	1.3132** (2.8262)	2.3709** (2.6865)	0.2675 (0.7375)
Control variables	Included	Included	Included	Included
Sample size	330	121	88	121
R^2	0.4801	0.5412	0.6397	0.5529

*$p < 0.05$, **$p < 0.01$.

models organized around three theoretically grounded channels—quality, efficiency and dynamism. We first quantify the direct association between the rural digital economy and rural industrial development, and then assess whether and how each channel transmits (mediation) and amplifies (moderation) this association, with attention to regional heterogeneity. The main findings are as follows:

First, the rural digital economy is positively associated with rural industrial development across all regions. The magnitude is greatest in the central region, followed by the western and then the eastern region, challenging the notion that digital dividends accrue primarily to the east. This establishes the baseline upon which mechanism tests are interpreted. Quality transformation significantly transmits the effect of the rural digital economy to industrial development, consistent with the hypothesis that digitalization reduces information asymmetries and transaction costs and strengthens branding and traceability. The mediating contribution is especially pronounced in the western region. Quality also strengthens the digital economy–industry link, with the moderating effect largest in the eastern region. Together, these results indicate that quality acts both as a conduit and an amplifier of digital impacts, in line with H1.

Second, efficiency transformation is a robust mediator overall and is the dominant transmission channel in the eastern region, consistent with the view that digital tools optimize factor use and improve value-chain coordination. Efficiency also amplifies the digital effect, with the strongest moderation in the central region, followed by the western, and comparatively weaker moderation in the eastern region. This pattern is consistent with H2, suggesting that where allocative frictions are higher, efficiency gains translate more strongly into industrial upgrading.

Third, dynamism significantly mediates the pathway from digitalization to industrial development, with particularly strong transmission in the western region—consistent with digital infrastructures enabling new business models aligned with local endowments. Dynamism additionally amplifies the digital effect, with the central region exhibiting the largest moderation. The eastern and western regions show comparatively weaker moderation. These findings align with H3 and point to a complementary role for entrepreneurship and cluster formation in sustaining growth.

Taken together, the evidence supports a three-channel mechanism through which the rural digital economy promotes rural industrial development: quality reduces market frictions, efficiency optimizes resource allocation and value-chain performance, and dynamism seeds new growth domains. The channels are jointly operative but differ in salience by region—efficiency dominates transmission in the east, whereas quality and dynamism are especially consequential in the west; the central region shows the largest overall direct effect and the strongest moderating roles for efficiency and dynamism. This pattern implies that policy priorities should be region-specific: accelerating supply-chain and factor-market integration in the east, deepening quality signaling and entrepreneurship ecosystems in the west, and leveraging efficiency- and innovation-led amplification in the central region.

Our results extend a rapidly growing literature on digitalization and structural change by relocating the center of gravity from cities and coastal provinces to China's rural heartlands. Prior studies emphasize urban-centered digital dividends and eastern-province advantages (Zhang et al., 2021; Chen and Wu, 2021). By contrast, we show that the rural digital economy promotes rural industrial development across all regions—with the largest direct association in the central region and sizeable effects in the western region—qualitatively challenging the east-first narrative. This pattern is consistent with diffusion dynamics whereby later-developing regions, once basic infrastructure is in place, realize outsized marginal gains from digital adoption.

Beyond documenting a positive average effect, we open the black box through a mechanism architecture that mirrors the hypotheses: quality, efficiency and dynamism. The literature typically attributes digital benefits to productivity improvements and value-chain coordination (Liu et al., 2022; Lei and Wang, 2023), but often treats impacts as linear and spatially uniform. Our evidence instead shows that all three transformations both transmit (mediation) and amplify (moderation) the digital economy's influence, with marked regional differentiation. Quality and dynamism mediate most strongly in the west, while efficiency is the dominant mediator in the east; on the amplification margin, efficiency and dynamism moderate most in the central region, and quality moderates most in the east. This heterogeneity aligns with theory: where information frictions are high and branding/traceability are scarce, quality improvements carry more weight; where allocative frictions bind, efficiency gains bite hardest; and where entrepreneurial ecosystems are nascent, dynamism catalyzes new activity. These nuances refine prior accounts and move beyond one-size-fits-all interpretations of "digital uplift" (Liu et al., 2022; Lei and Wang, 2023; Wang et al., 2025).

Our findings also converse with emerging work on the distributional consequences of rural digitalization. While recent research cautions that digital expansion can reshape intra-rural inequality (Wang et al., 2025), our mechanism dissection helps identify where and how inclusive growth can be engineered: by leveraging quality to lower search and certification costs for small producers, deploying efficiency tools (logistics platforms, e-commerce integration) where factor misallocation is acute, and nurturing dynamism via entrepreneurship supports and cluster formation. In short, the digital economy is not merely a growth input; it is a transformation enabler whose effects depend on the local binding constraint.

5.2 Theoretical contributions

Digital transformation has become a defining force in reshaping economic systems, yet its mechanisms of influence on rural industries remain under-theorized. Our study advances theory by integrating quality, efficiency, and vitality into a unified analytical framework for industrial development in the digital economy. This framework reveals how digitalization does more than boost productivity: it reconfigures the logic of growth, shifting rural industries from scale-driven expansion toward precision-based and innovation-led models.

By demonstrating the mediating and moderating roles of quality, efficiency, and vitality, we extend existing theories of industrial upgrading. In particular, our findings clarify the pathways through which digital technologies restructure value chains, reduce systemic risk, and accelerate the convergence of traditional and emerging sectors. This contribution builds on prior research on spillover effects of digital transformation (Du and Lou, 2022), the empowerment of rural revitalization (Meng et al., 2023), and the dynamics of structural upgrading in digitalized rural economies (Li and Wang, 2023). It moves beyond single-factor explanations by showing how the interplay of multiple transformations governs industrial resilience and competitiveness.

Methodologically, we enrich the field by operationalizing multidimensional indicators of quality, efficiency, and vitality. This dual qualitative–quantitative approach strengthens empirical evaluation and enhances the reproducibility of theory-driven insights. Conceptually, it deepens understanding of how digital economies generate spillover effects that transcend sectoral boundaries, creating new organizational forms and business models while optimizing traditional structures. These insights also align with global evidence that digitalization drives sustainable development and fosters economic diversification across contexts (Li and Wang, 2023; Li et al., 2022; Ren et al., 2022).

Together, these contributions establish a theoretical foundation for analyzing how digitalization shapes rural modernization. They provide a transferable framework for future studies of economic transformation in diverse settings, from emerging economies to advanced industrial contexts (Asmyatullin and Glavina, 2025; Neffati and Jbir, 2024).

5.3 Practical implications

This study highlights the transformative potential of the rural digital economy in catalyzing rural industrial development. While the findings draw on the Chinese context, the mechanisms identified—namely the mediating and moderating roles of quality, efficiency, and dynamism transformations—are conceptually transferable to rural settings globally, particularly in emerging and developing economies facing similar structural constraints.

First, efforts should be made to improve farmers' digital literacy and narrow the urban–rural digital divide. Currently, digitally skilled, multifunctional professionals engaged in agricultural production are scarce. Digital literacy training for farmers relies heavily on government policy support and funding, yet coordination among relevant departments remains limited, particularly in terms of information exchange and data sharing. As the primary agents of agricultural production, farmers must be equipped to integrate digital technologies across the agricultural value chain—from production and processing to sales. A coordinated approach involving government leadership, social participation, and data sharing could help establish collaborative training platforms. In particular, the central and western regions, where digital capacity lags behind, should develop localized digital learning platforms tailored to farmers, with low barriers to entry and intelligent delivery mechanisms. Increased public investment in digital human capital development is also critical to improving the overall quality of the rural digital workforce.

Second, the spatial layout of specialized agricultural industries should be optimized to enhance both the scale and quality of digital empowerment in rural revitalization. This includes strengthening digital agricultural infrastructure, promoting the industrialization of digital agriculture, and facilitating the widespread adoption of smart agricultural technologies. The expansion of internet coverage into rural areas, along with the application of tools such as agricultural big data and artificial intelligence, can foster multifunctional rural economies and accelerate the modernization of agricultural industries. The application of next-generation information and data technologies should transform agricultural production models and business structures. Given the heterogeneity in regional resource endowments, digital agricultural strategies must be tailored to local comparative advantages. Aligning with regional agricultural development plans, digital resources should be allocated rationally across production, processing, and distribution stages, thereby enhancing the competitiveness of the entire agricultural value chain and narrowing interregional and urban–rural digital divides in agriculture.

Third, strengthening quality transformation is essential to building a solid foundation for rural industrial development. Enhancing the quality of the rural industrial supply system in line with international standards is critical. As consumer demand shifts from sufficient food to better food, the focus of rural industry must evolve accordingly. Extending upstream and downstream segments of the rural industrial chain, increasing investment in indigenous R&D, and overcoming bottlenecks in core technologies are necessary to boost the quality and resilience of rural industries. Technological innovation must be leveraged to activate local production factors and foster innovation in technology, management, and institutional mechanisms through a contribution-based factor market system.

Fourth, efficiency transformation should be pursued to revitalize rural industries. Many rural industries currently fail to meet evolving market demands, leading to ineffective supply and overcapacity in certain sectors, while scarce resources are not optimally allocated to more competitive industries. Industrial restructuring, guided by local resource endowments, should aim to improve efficiency and foster emerging industries. As rising factor costs become an undeniable constraint, enhancing efficiency through innovation is imperative. The integration of big data and artificial intelligence with traditional industries can enable deep technological transformation, improve productivity, and unlock new vitality in rural industrial systems—breathing new life into legacy sectors while optimizing new ones.

Fifth, dynamism transformation must be emphasized to cultivate new drivers of rural industrial growth. Talent, enterprise vitality, and institutional environments are at the core of this transformation. As China's demographic dividend wanes, talent development is key to ensuring sustained human capital appreciation. Targeted strategies are needed to attract and retain talent in rural areas and address structural imbalances in the rural workforce. Furthermore, a persistent gap exists between technological innovation and commercialization. Although large volumes of research output are generated annually, the rate of industrial application remains low. It is therefore essential to not only stimulate innovation but also ensure its translation into tangible outcomes that serve rural industries. Strengthening intellectual property protection in agriculture will help preserve the competitive advantage of innovations and foster endogenous drivers of rural industrial modernization.

5.4 Limitations and future directions

This study offers valuable insights into how the rural digital economy drives rural industrial development via quality, efficiency, and dynamism transformations, yet several limitations remain. The use of provincial-level data may mask local variations, calling for finer-grained analyses using county or village data. The largely static modeling framework overlooks the temporal and recursive nature of digital-industrial transitions. Moreover, findings rooted in China's institutional context may not fully generalize to other regions with different socioeconomic or policy environments. Finally, the assumed independence of quality, efficiency, and dynamism may oversimplify their likely interdependent dynamics. Future research should explore these complexities using more granular data, dynamic models, and cross-country comparisons.

6 Conclusion

This study demonstrates that the rural digital economy is a key catalyst for rural industrial development, acting both directly and through regionally differentiated pathways of transformation. Quality, efficiency, and dynamism emerge not only as mediators but also as moderators in this relationship, underscoring their dual role in amplifying the developmental effects of digitization. The findings challenge conventional assumptions about regional digital advantages, revealing stronger impacts in less developed areas. By integrating transformation mechanisms into the analysis, this work refines our understanding of how digital tools can reconfigure industrial dynamics in rural contexts. These insights hold relevance beyond China, offering a conceptual foundation for digital-led rural revitalization strategies globally.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

XJ: Software, Writing – original draft, Funding acquisition, Methodology, Data curation, Validation. TZ: Conceptualization, Writing – review & editing, Funding acquisition, Resources, Formal analysis, Project administration.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was supported by the General Project of the National Social Science Fund of China (21BJY210), Anhui Philosophy and Social Sciences Planning Key Project (AHSKD2023D024), Outstanding Youth Research Project of Anhui Universities (2022AH020030), the Science Foundation of the Ministry of Education of China (21YJCZH252), the Science Foundation for the Excellent Youth Scholars of Universities in Anhui Province (2023AH030033), the Science Foundation for Postdoctoral Research Projects in Sichuan Province (TB2023088), the Philosophy and Social Science Foundation of Anhui Province (AHSKQ2021D17), the Anhui Provincial Quality Engineering Project (2023kcszsf055), and the New Era Education Quality Engineering Project (2023qyw/sysfkc018).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Aghion, P., and Howitt, P. (1992). A model of growth through creative destruction. *Econometrica* 60, 323–351. doi: 10.2307/2951599

Akerlof, G. A. (1970). The market for "lemons": quality uncertainty and the market mechanism. *Q. J. Econ.* 84, 488–500. doi: 10.2307/1879431

Arrow, K. J. (1962). The economic implications of learning by doing. *Rev. Econ. Stud.* 29, 155–173. doi: 10.2307/2295952

Asmyatullin, R. R., and Glavina, S. G. (2025). Digitalization as a driver for sustainable development in the GCC economies. *Unconv. Res.* 8:100231. doi: 10.1016/j.uncres.2025.100231

Brynjolfsson, E., and Hitt, L. M. (2003). Computing productivity: firm-level evidence. *Rev. Econ. Stat.* 85, 793–808. doi: 10.1162/003465303772815736

Chen, S., and Chen, D. (2017). Dynamic evolution of resource allocation efficiency in China: a new perspective on incorporating energy factors. *Soc. Sci. China* 4, 67–207.

Chen, W., and Wu, Y. (2021). Digital economy's development, digital divide and the income gap between urban and rural residents. *South China J. Econ.* 11, 1–17. doi: 10.19592/j.cnki.scje.390621

Coase, R. H. (1937). The nature of the firm. *Economica* 4, 386–405. doi: 10.1111/j.1468-0335.1937.tb00002.x

Cong, H., and Zhang, C. Y. (2022). Digital technology and companies' high-quality innovation. *J. Zhongnan Univ. Econ. Law.* 4, 29–40. doi: 10.19639/j.cnki.issn1003-5230.2022.0038

Du, Y., and Lou, J. (2022). The impact and spillover effect of digital transformation on enterprise upgrading. *J. Zhongnan Univ. Econ. Law.* 5, 119–133. doi: 10.19639/j.cnki.issn1003-5230.2022.0062

Eduard, C., Yolanda, M., Berta, F., and Natalia, D. Rural cooperatives in the digital age: an analysis of the internet presence and degree of maturity of Agri-food cooperatives' e-commerce. *J. Rural. Stud.* 2019, 74, 55–66. doi: 10.1016/j.jrurstud.2019.11.0112020

Farrell, M. J. (1957). The measurement of productive efficiency. *J. R. Stat. Soc. Ser. A Stat. Soc.* 120, 253–290. doi: 10.2307/2343100

Gereffi, G., Humphrey, J., and Sturgeon, T. (2005). The governance of global value chains. *Rev. Int. Polit. Econ.* 12, 78–104. doi: 10.1080/09692290500049805

Hsieh, C.-T., and Klenow, P. J. (2009). Misallocation and manufacturing TFP in China and India. *Q. J. Econ.* 124, 1403–1448. doi: 10.1162/qjec.2009.124.4.1403

Hu, P. (2023). High-quality economic development in China: a literature review. *J. Shanxi Univ. Financ. Econ.* 45, 43–53. doi: 10.13781/j.cnki.1007-9556.2023.07.004

Jia, X. M. (2023). Digital economy, factor allocation, and sustainable agricultural development: the perspective of labor and capital misallocation. *Sustainability* 15:4418. doi: 10.3390/su15054418

Jiang, Q. Z., Li, H., and Liu, X. T. (2019). The measurement of the development level of digital inclusive finance in rural areas and its influencing factors. *Financial Econ. Res.* 34, 123–133.

Lang, Y. K., Fan, B. N., Zeng, C. Y., and Huang, S. Q. (2025). The driving mechanism and enhancement path of digital economy for industrial leapfrogging: based on the mediating role of science and technology innovation and the regulating effect of industrial ecology. *Stud. Sci. Sci.* 43, 358–370. doi: 10.16192/j.cnki.1003-2053.20240628.005

Lei, Z., and Wang, D. (2023). Digital transformation and total factor productivity: empirical evidence from China. *PLoS One* 18:e0292972. doi: 10.1371/journal.pone.0292972

Leibenstein, H. (1966). Allocative efficiency vs. X-efficiency. *Am. Econ. Rev.* 56, 392–415.

Li, Z. G., Hu, K., and Shi, Q. Y. (2025). The influence of digital village construction on agricultural green development-based on the mediate role of industrial structure upgrading. *Front. Sustain. Food Syst.* 8:1538845. doi: 10.3389/fsufs.2024.1538845

Li, H., and Li, Z. (2024). The impact of digital transformation on high quality development and high speed growth of enterprises: from the perspective of quality, efficiency, and incentive changes. *Chin. Rural Econ.* 4, 120–140. doi: 10.20077/j.cnki.11-1262/f.2024.04.007

Li, Z. X., Liu, C. J., and Chen, X. H. (2022). Power of digital economy to drive urban-rural integration: intrinsic mechanism and spatial effect, from perspective of multidimensional integration. *Int. J. Environ. Res. Public Health* 19:15459. doi: 10.3390/ijerph192315459

Li, X. H., and Wang, X. Y. (2023). Rural digitalization, farmers' entrepreneurship and the upgrading of rural industrial structure: dynamic analysis of PVAR based on Chinese provincial panel data. *World Survey Res.* 6, 60–70. doi: 10.13778/j.cnki.11-3705/c.2023.06.006

Li, X. Z., and Zhang, J. (2017). A comparative study on the regional differences of agricultural informatization readiness level in China. *Inf. Sci.* 35, 55–62. doi: 10.13833/j.cnki.is.2017.10.011

Liang, J. (2024). Digital infrastructure, diversified development of rural industries and Chinese-style agriculture and rural modernization. *Statist. Decis.* 40, 40–45. doi: 10.13546/j.cnki.tjyjc.2024.11.007

Lin, J. Y. (2012). New structural economics: A framework for rethinking development and policy. London: World Bank.

Liu, J. R., Feng, X. J., Liu, J. X., and Yamaka, W. (2024). Digital economy and industrial structure transformation: mechanisms for high-quality development in China's agriculture and rural areas. *Agriculture* 14:1769. doi: 10.3390/agriculture14101769

Liu, Y., Yang, Y., Li, H., and Zhong, K. (2022). Digital economy development, industrial structure upgrading and green total factor productivity: empirical evidence from China's cities. *Int. J. Environ. Res. Public Health* 19:2414. doi: 10.3390/ijerph19042414

Lu, Z. Y., Yang, L. Q., Gou, D., and Wu, Z. Y. (2025). Promotion of rural industrial revitalization through the development of the rural digital economy. *Front. Sustain. Food Syst.* 9:1598461. doi: 10.3389/fsufs.2025.1598461

Marshall, A. (1890). Principles of economics. New York, NY: Macmillan.

Meng, W. F., Zhang, G. M., and Zhao, F. Y. (2023). Digital economy empowers rural revitalization: influencing mechanisms and spatial effects. *Res. Financ. Econ.* 3, 32–44. doi: 10.19654/j.cnki.cjwtyj.2023.03.003

Mol, A. P. J., and Spaargaren, G. (2000). Ecological modernization theory in debate: a review. *Environ. Polit.* 9, 17–49. doi: 10.1080/09644010008414511

Moretti, E. (2010). Local multipliers. *Am. Econ. Rev.* 100, 373–377. doi: 10.1257/aer.100.2.373

Mu, J., and Ma, L. P. (2021). Measurement of China's agricultural and rural digital economy development index and regional characteristics. *J. South China Agric. Univ.* 20, 90–98.

Neeraj, S., Avinash, K., and Kushankur, D. (2023). Unlocking the potential of knowledge economy for rural resilience: the role of digital platforms. *J. Rural. Stud.* 104:103164. doi: 10.1016/j.jrurstud.2023.103164

Neffati, M., and Jbir, R. (2024). The impact of digitalization and economic diversification on economic growth: evidence from Saudi Arabia. *Technol. Econ. Dev. Econ.* 30, 1510–1532. doi: 10.3846/tede.2024.22105

Ohlin, B. (1933). Interregional and international trade. Boston, MA: Harvard University Press.

Porter, M. E. (1998). Clusters and the new economics of competition. *Harv. Bus. Rev.* 76, 77–90.

Porter, M. E., and van der Linde, C. (1995). Toward a new conception of the environment–competitiveness relationship. *J. Econ. Perspect.* 9, 97–118. doi: 10.1257/jep.9.4.97

Qin, Z., Pei, X., Andrianarimanana, M., and Weng, S. (2023). Digital inclusive finance and the development of rural logistics in China. *Heliyon* 9:e17329. doi: 10.1016/j.heliyon.2023.e17329

Qin, Z. H., Tian, J. X., and He, Y. (2023). How dose digital economy drive high-quality development of rural industries: analysis based on the misallocation of labor and capital factors. *World Agric.* 7, 40–51. doi: 10.13856/j.cn11-1097/s.2023.07.004

Ren, J. M., Zheng, C. R. Y., Guo, F. Y., Zhao, H. B., Ma, S., and Cheng, Y. (2022). Spatial differentiation of digital rural development and influencing factors in the Yellow River Basin, China. *Int. J. Environ. Res. Public Health* 19:16111. doi: 10.3390/ijerph192316111

Romer, P. M. (1990). Endogenous technological change. *J. Polit. Econ.* 98, S71–S102. doi: 10.1086/261725

Schumpeter, J. A. (1934). The theory of economic development. Boston, MA: Harvard University Press.

Shao, K., Ma, R., and Joseph, K. (2023). An in-depth analysis of the entrepreneurship of rural Chinese mothers and the digital inclusive finance. *Telecomm. Policy* 47:102593. doi: 10.1016/j.telpol.2023.102593

Shen, Y., and Li, J. R. (2023). Co-prosperity effect and spatial differentiation of digital inclusive finance on integrated development of rural industries. *J. South China Agric. Univ.* 22, 82–95.

Shen, J., and Wang, Y. (2019). Research on the evaluation index system of agricultural informatization level in China. *Trans. Chin. Soc. Agric. Eng.* 35, 162–172.

Shu, Z., and Wang, C. (2024). The inner logic of digital economy empowering high quality economic development. *Sci. Manage.* 44, 30–36.

Solow, R. M. (1957). Technical change and the aggregate production function. *Rev. Econ. Stat.* 39, 312–320. doi: 10.2307/1926047

Spence, M. (1973). Job market signaling. *Q. J. Econ.* 87, 355–374. doi: 10.2307/1882010

Stigler, G. J. (1961). The economics of information. *J. Polit. Econ.* 69, 213–225. doi: 10.1086/258464

Su, Y. Z., Liu, M. Q., Deng, N., Cai, Z. J., and Zheng, R. R. (2024). Rural digital economy, agricultural green technology innovation, and agricultural carbon emissions-based on panel data from 30 provinces in China between 2012 and 2021. *Pol. J. Environ. Stud.* 33:4630. doi: 10.15244/pjoes/184630

Tang, Y., and Sun, Y. J. (2024). The impact of high-quality development of rural industries on the transformation of arable land use function. *Acad. Exch.* 2, 93–109.

Tian, Y., Liu, Q., and Huang, J. (2023). The mechanism of digital economy enabling rural industrial revitalization: based on the case analysis of three typical towns in Zigui county, Hubei province. *Issues in Agricultural Economy* 12, 36–46. doi: 10.13246/j.cnki.iae.2023.12.005

Tian, Y., Ye, Y. T., Huang, J., and Liu, Q. (2022). The internal mechanism and empirical test of rural industrial revitalization driven by digital economy: based on the mediating effect of urban and rural integration development. *Issues Agric. Econ.* 10, 84–96. doi: 10.13246/j.cnki.iae.2022.10.003

Wang, C. (2022). The theory, mechanism, and strategy of the integration and development of digital economy and traditional industries. *J. Commer. Econ.* 8, 190–192.

Wang, H., Leng, H., and Yuan, M. (2025). From opportunity to inequality: how the rural digital economy shapes intra-rural income distribution. *Humanit. Soc. Sci. Commun.* 12, 1–14. doi: 10.1057/s41599-025-04848-2

Wang, Y., Peng, Q., Jin, C., Ren, J., Fu, Y., and Yue, X. (2023). Whether the digital economy will successfully encourage the integration of urban and rural development: a case study in China. *Chin. J. Popul. Resour. Environ.* 21, 13–25. doi: 10.1016/j.cjpre.2023.03.002

Wang, D. X., and Ran, X. M. (2022). Rural digitalization, human capital and integrated development of rural industries: empirical evidence based on China provincial panel data. *J. Chongqing Univ.* 28, 1–14.

Wang, Z., and Ren, B. (2019). Analysis of the restrictive factors and paths of efficiency transformation in China's high quality development. *Res. Financ. Econ. Issues* 6, 25–32. doi: 10.19654/j.cnki.cjwtyj.2019.06.004

Wang, F. T., Wang, H., and Xiong, L. C. (2024). Does the digital economy exhibit multiplier effects? A case study on the optimization of agricultural production structure in rural digital economy. *Int. J. Agric. Sustain.* 22:2386821. doi: 10.1080/14735903.2024.2386821

Williamson, O. E. (1985). The economic institutions of capitalism: Firms, markets, relational contracting. London: Free Press.

Wu, G. Y., Pang, G. G., Tang, J. H., and Liu, J. D. (2022). Measurement, regional difference and spatial-temporal evolution of the development level of China's rural digital economy. *J. Hunan Agric. Univ.* 23, 15–27. doi: 10.13331/j.cnki.jhau(ss).2022.04.002

Xin, L., Liu, H., and Hu, Z. Q. (2021). The temporal and spatial evolution and influencing factors of China's agricultural and rural modernization. *Econ. Rev. J.* 12, 101–114. doi: 10.16528/j.cnki.22-1054/f.202112101

Xu, X., Li, S., and Wang, X.etc (2018). The choice of China's economic growth target: ending the "collapse theory" with high quality development. *J. World Econ.* 41, 3–25. doi: 10.19985/j.cnki.casjwe.2018.10.002

Xu, M., Xu, Y., and Yang, M. (2018). Technological change, innovation system, and agricultural development in Brazil: endogenous drivers and areas of cooperation between China and Brazil. *Sci. Technol. Manage. Res.* 38, 128–133.

Yan, M. Y., and Cao, X. Z. (2024). Digital economy development, rural land certification, and rural industrial integration. *Sustainability* 16:4640. doi: 10.3390/su16114640

Yu, D., Yang, L., and Xu, Y. (2022). The impact of the digital economy on high-quality development: an analysis based on the national big data comprehensive test area. *Sustainability* 14:14468. doi: 10.3390/su16093611

Zhang, J. S. (2023a). The internal mechanism and empirical test of digital economy driving the diversified development of rural industries. *Econ. Probl.* 9, 44–51. doi: 10.16011/j.cnki.jjwt.2023.09.003

Zhang, X. L. (2023b). The core issues and countermeasures of digital economy supporting rural revitalization. *Southwest Finance* 2023, 95–106.

Zhang, W., and Bai, Y. X. (2022). Theoretical construction, empirical analysis and optimization path of the coupling of digital economy and rural revitalization. *Chin. Soft Sci.* 1, 132–146.

Zhang, X., Luo, R., Shi, Y., and Shangguan, Y. (2021). How digital economy helps rural poverty alleviation and rural revitalization in China. *E3S Web Conf.* 275:01058. doi: 10.1051/e3sconf/202127501058

Zhang, L., Xu, Z. M., and Li, C. L. (2023). The impact of rural digital economy development on farmers' income growth. *J. Jiangxi Univ. Finan. Econ.* 3, 82–94. doi: 10.13676/j.cnki.cn36-1224/f.2023.03.011

Zhao, X., and Li, C. (2012). Transformation of agricultural product distribution channels: evolutionary laws, dynamic mechanisms, and development trends. *J. Manage. World* 3, 81–95. doi: 10.1974/j.cnki.11-1235/f.2012.03.008

Zhou, X. D., and Zhou, Y. (2021). Digital economy facilitates the revitalization of rural industry: mechanism, obstacle and path. *Grain Sci. Technol. Econ.* 46, 21–26. doi: 10.16465/j.gste.cn431252ts.20210505