

THE IMPACT OF RURAL E-COMMERCE DEVELOPMENT IN NORTHERN ANHUI ON REGIONAL INNOVATION EFFICIENCY

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Abstract: E-commerce assistance for agriculture provides new momentum for economic development and rural revitalization. Taking rural areas in northern Anhui as the research subject, this study investigates the impact of rural e-commerce on regional innovation efficiency. The findings indicate that the overall scale of rural e-commerce in northern Anhui has steadily grown, giving rise to distinctive products and brands, and establishing an innovative model involving multiple stakeholders. Patent applications and the number of high-tech enterprises in the region have shown a trend of steady growth with improved quality, accompanied by continuous increases in R&D investment and rapid growth in technology contract transaction volumes. Furthermore, the relationship between rural e-commerce and innovation efficiency reveals that e-commerce expands market opportunities and optimizes resource allocation, thereby stimulating innovation vitality, reducing innovation costs, and directly enhancing regional innovation efficiency. Additionally, through industrial agglomeration and attracting innovative talent, it indirectly promotes improvements in regional innovation efficiency. Based on these conclusions, relevant recommendations are proposed to support the strategic goal of rural revitalization in northern Anhui.

Keywords: E-commerce; E-commerce supporting agriculture; Regional innovation; Innovation efficiency; Rural revitalization

1 INTRODUCTION

The development of e-commerce has facilitated people's lives and promoted the high-quality development of regional economies. To achieve rural revitalization, e-commerce has continuously expanded its reach to underdeveloped rural areas and holds significant importance in the country's rural strategy implementation. With the implementation of the rural e-commerce strategy, while promoting the rapid development of rural economies, it has also enhanced regional innovation. For instance, in the Anhui Province's northern region, from 2021 to 2023, the average annual growth rate of regional rural product online sales was 20%, with total amounts reaching 80 billion yuan, 100 billion yuan, and 120 billion yuan respectively. The rapid development of rural e-commerce in the northern region of Anhui has not only solved the sales problems of agricultural products in the region but also brought about development funds and technologies to the northern region. Under the influence of rural e-commerce, many e-commerce incubation parks have been established in the northern region of Anhui, promoting economic development while also driving the level and progress of regional innovation in the northern region, accelerating the transformation of the production structure in the northern region and the pace of rural revitalization. Therefore, studying the impact of rural e-commerce development in the northern region of Anhui on regional innovation efficiency has certain typical significance.

Scholars have conducted a series of studies on regional innovation, such as proposing the "Regional Innovation System" (RIS) theory, which emphasizes the impact of geographical proximity and institutional thickness on innovation [1]. With further research, the university-industry-government triple helix model was introduced to explain the dynamics of regional innovation [2], focusing on interactions among specific innovation actors. Studies have also examined the effects of three types of proximity—geographical, cognitive, and institutional—on innovation [3]. Beyond directly related actors, regional innovation systems also involve indirect participants [4-6]. Some scholars, however, question this framework, arguing that a regional innovation system is a network of interconnected entities within a specific region capable of adopting and disseminating new technologies, forming a social system composed of relevant societal actors [7-8]. Given the territorial embeddedness of regional innovation systems, the regional innovation environment is regarded as an essential component, one of the key factors influencing both regional innovation levels and development. These two elements interact dynamically, driving advancements in regional innovation [9-10]. Regarding the relationship between the digital economy and innovation performance, researchers have found that China's internet development level significantly and positively affects regional innovation efficiency, serving as a major driver for improving current regional innovation outcomes [11]. They also argue that data element allocation is a critical focus for advancing high-quality digital development, while industrial innovation upgrading is a vital lever for accelerating the cultivation of new productive forces [12-14]. Clearly, numerous studies have explored factors influencing regional innovation; however, systematic research on the impact of rural e-commerce in specific local areas remains underdeveloped. Therefore, this study takes northern Anhui Province as its case, analyzing the current status of rural e-commerce development and regional innovation input-output in the region, exploring both direct and indirect

relationships between them. It aims to provide insights for integrating rural e-commerce growth with enhanced regional innovation efficiency in northern Anhui, offering valuable references for promoting rural revitalization in other regions.

2 E-COMMERCE AND REGIONAL INNOVATION IN RURAL AREAS OF NORTHERN ANHUI

2.1 The Current Development of E-commerce in Rural Areas of Northern Anhui

2.1.1 Overall scale and regional performance

The overall scale and regional performance of e-commerce in rural areas of Northern Anhui are shown in Table 1.

Table 1 Core Indicators of Rural E-commerce in Northern Anhui (2024)

Index	Dangshan	Fuyang	North Anhui
E-commerce transaction volume (100 million yuan)	70	172.88	900
Proportion of agricultural products moving up the value chain	85.7%	68%	72%
The penetration rate of live-streaming for e-commerce sales	90%	75%	65%
Number of employees in the e-commerce industry (in ten thousand)	5.2	18.6	80
Number of people lifted out of poverty (in ten thousands)	1.2	3.5	12.8

As shown in Table 1, in 2024, the e-commerce transaction volume of the six cities in northern Anhui Province reached 90 billion yuan, with 800,000 employees and 128,000 people lifted out of poverty. Among them, Fuyang City, with a transaction volume of 17.288 billion yuan and 186,000 employees, occupied the core position in the region. While Dangshan County, as a county-level unit, performed outstandingly in structural indicators, with an upscaling of agricultural products reaching 85.7% and the penetration rate of live-streaming sales reaching 90%, both significantly higher than the average levels of Fuyang City and the six cities in northern Anhui Province. It presented a three-level differentiation feature of "county-level specialization, city-scale expansion, and regional expansion". Meanwhile, the poverty alleviation-driven rate decreased from 23.08% of Dangshan County to 16% of the six cities in northern Anhui Province, reflecting a marginal decreasing trend in the proportion of direct beneficiaries of poverty alleviation during the expansion of the e-commerce industry scale.

2.1.2 Product features and brand building

Northern Anhui has achieved remarkable strategic effects in building differentiated competitiveness relying on characteristic agricultural products, forming a multi-dimensional brand matrix and a pattern of coordinated industrial development. In terms of developing core single-product brands, Dangshan crisp pears have achieved a breakthrough of 2 million jin in single-session sales via the live-streaming mode starting with zero followers. Its online sales reached 3.5 billion yuan in 2024, accounting for 78% of the national crisp pear market share, and has become a benchmark for national agricultural-product live-stream e-commerce. By virtue of cross-border e-commerce, Huaiyuan pomegranates have accessed markets in Southeast Asia and the Middle East with an annual sales growth rate of 120%. Supported by the whole-industrial-chain construction of glutinous rice, its output value has exceeded 10 billion yuan, building up industrial advantages as "China's No.1 Glutinous Rice County". Adopting the innovative mode of "cooperative + cold-chain logistics + live-streaming", Xiaoxian grapes have witnessed a 40% rise in unit price and a drop of loss rate to 5%. Meanwhile, the coverage rate of standardized planting bases and green certification has exceeded 65%, establishing a whole-process quality assurance system from planting to consumption. In the field of intangible-cultural-heritage industrialization, Huanggang wickerwork generates an annual sales volume of 200 million yuan and drives employment for more than 2,000 farmers, setting a model for rural revitalization through "intangible cultural heritage + e-commerce". For regional public brand building, Mengcheng County has built a three-brand matrix including "Pindao Mengcheng" for pre-packaged food, "Naxian Xiangxia" for primary agricultural products and "Mengcheng Good Products" for intangible-cultural-heritage goods, covering the whole industrial chain of agricultural products. Supported by 18 cold-chain logistics bases and 100 village-level e-commerce integration outlets, it realizes the coordinated development of branding, standardization and digitalization. Focusing on circular agriculture, Lingbi County has incubated the regional public brand "Lingnong Bixuan" through ecological models such as "wheat-cow-mushroom" and "soybean-chicken-egg-fertilizer". It translates circular-agriculture technologies into product premium capacity and builds brand recognition as "a representative of China's circular agriculture".

2.1.3 Participants and model innovation

The participants and operational models of rural e-commerce in northern Anhui Province exhibit a diversified and innovative development pattern, forming a multi-level collaborative industrial ecosystem. In terms of the structure of participants, individual farmers, professional cooperatives, and leading enterprises constitute the three core forces: Over 50% of farmers have achieved self-production and self-sale through micro-commerce and community e-commerce, with an average annual income increase of 12,000 yuan per household. The flexibility and low entry barriers of these models have become key drivers for e-commerce adoption. Si County Haonidou Food Co., Ltd. leverages local agricultural advantages to establish a new e-commerce model characterized by "enterprise leadership, farmer participation, digital empowerment, and full-chain operations." Regarding collaboration among stakeholders, the company integrates scattered farming and breeding resources from surrounding areas, promotes standardized production and unified quality control systems, and engages more than 600 households in the supply chain, effectively broadening farmers' income channels and increasing average annual earnings by 11,000 yuan per household, significantly enhancing the competitiveness of agricultural products in the market. Operationally, the company breaks free from

traditional offline sales constraints by building a digital management system and establishing diverse online channels such as e-commerce platforms, live-streaming sales, and community distribution, supported by a comprehensive cold-chain warehousing and logistics network, thus creating a closed-loop integration of production and sales. In 2024, the company achieved sales of 240 million yuan, realizing digital transformation of traditional agriculture while driving the development of regional e-commerce supporting industries, providing a replicable model for large-scale and branded growth of county-level agricultural e-commerce in northern Anhui.

Table 2 Comparison of E-commerce Models in Northern Anhui

Model	Typical Cases	Core Advantage
Livestream E-commerce	Dangshan Sweet Pear "Zero Fans Started the Account"	The traffic has experienced an explosive growth and the user trust level is high.
Community E-commerce	Guoyang "Guozhen Fresh Life Hall,"	Accurately reach "die-hard fans" at a low cost
The Entire Industrial Chain E-commerce	HuaiShang Group's "Farm to Table"	Quality is controllable and the profit margin is large.

Based on Table 2, three mainstream rural e-commerce models have emerged in northern Anhui: live-streaming e-commerce, community-based e-commerce, and full-industry-chain e-commerce. Live-streaming e-commerce is exemplified by the "zero-follower launch" of Dangshan pear brand, which leverages short-video livestreams to rapidly generate traffic and enhances user trust through scenario-based presentations, although competition for traffic remains intense. Community-based e-commerce is typified by Guoyang "Guozhen Fresh Life Hall", which maintains loyal customers through private community engagement, resulting in low customer acquisition costs but relatively limited market reach. Full-industry-chain e-commerce primarily follows the "farm-to-table" model of Huai Shang Group, integrating the entire production and sales chain to ensure product quality control and substantial profit margins, though it requires significant initial investment in infrastructure. Each model has its strengths and weaknesses, and different business entities can select suitable approaches based on their respective resources, jointly promoting diversified development of agricultural e-commerce in northern Anhui.

2.1.4 Financial support and infrastructure

At the policy guarantee level, Anhui Province has set aside 5 billion yuan as a special support fund for rural e-commerce. Through policy tools such as entrepreneurship subsidies (ranging from 10,000 to 100,000 yuan) and logistics subsidies (reducing rental costs by 30% to 70%), it provides precise empowerment. The "Leading County" plan is implemented, aiming to create 20 e-commerce demonstration counties and 200 "Anhui Local Specialties" brands by 2027, forming a differentiated development pattern of "one county for one industry, one town for one specialty". In terms of infrastructure construction, the logistics network has achieved "delivery to every village", with the coverage rate of logistics sorting centers in towns reaching 90%. The delivery time for fresh products has been reduced from 48 hours to 24 hours, effectively solving the "first mile" problem. Digital infrastructure has achieved 4G/5G network coverage in all administrative villages, and the agricultural product traceability system has been used to conduct full-process digital supervision for over 60% of characteristic products, building a "from the field to the cloud" quality traceability system. Among them, key areas such as Mengcheng County have built 18 modern cold chain bases, reducing the fresh product loss rate to 8%. Simultaneously, 100 village-level e-commerce service integration outlets have been constructed (Table 3), forming a three-level service system of "county center, town station, village outlet".

Table 3 Cold-Chain Infrastructure and Coverage in Northern Anhui

Project	Mengcheng	Dangshan	Fuyang
Number of cold chain bases (units)	18	12	25
Fresh produce loss rate	8%	10%	12%
Number of households covered (ten thousand)	2.3	1.8	4.5

2.1.5 Basic models of rural e-commerce in Anhui North Region

The rural e-commerce models in Anhui North Region are diverse. One is the government-led model. The government, through measures such as formulating policies, building infrastructure, and providing financial support, creates a favorable environment for the development of rural e-commerce. For example, Dangshan County, led by the government, treats rural e-commerce as a closely related field to county-level e-commerce, economic development, and rural revitalization. It introduces advanced e-commerce models and skills through Alibaba, JD, etc., and establishes rural Taobao service stations to facilitate farmers' quick e-commerce shopping. At the same time, the county government focuses on e-commerce talent cultivation and regularly offers various e-commerce training courses. Experts and e-commerce enterprise leaders give farmers e-commerce knowledge to enhance their e-commerce awareness and knowledge level. Emphasis is placed on brand building, and Dangshan pear and Dangshan yellow peach, agricultural product brands are created to enhance brand awareness and market competitiveness through e-commerce platforms. The second model is the enterprise-led model. The enterprises in Anhui North Region, leveraging their own advantages such as funds, technology, and talents, play a role of innovation and leading demonstration in rural e-commerce development. They establish e-commerce operation centers, logistics distribution centers, and integrate rural e-commerce resources to promote the improvement of the rural e-commerce industry chain. Three-Squirrel has established agricultural product procurement bases in rural Anhui, jointly purchasing high-quality agricultural products from local farmers and rural

cooperatives, conducting agricultural product processing and sales. Three-Squirrel uses its own e-commerce platform and brand reputation to sell agricultural products from rural Anhui across the country, enhancing the added value of agricultural products. The third model is the farmer self-employment model. Farmer self-employment has become a new type of rural e-commerce. By establishing online stores, micro-stores, they sell agricultural products.

2.2 The Current Situation of Innovation Input and Output in the Northern Anhui Region

For the analysis of the current situation of innovation input and output in the Northern Anhui region, comparisons are mainly made in three aspects: patent applications, the number of high-tech enterprises, and the transaction volume of technology contracts.

2.2.1 Number of patent applications

Table 4 Number of Patent Applications (Pieces)

Year	Fuyang	Bozhou	Suzhou	Bengbu	Huainan	Huaibei
2019	5200	2300	2800	4500	1500	1200
2020	5800	2700	3200	5000	1800	1500
2021	6500	3100	3800	5800	2100	1800
2022	5608	2944	4157	4100	2500	2826
2023	5211	3017	4752	4500	3000	3000

Data source: Anhui Provincial Bureau of Statistics and the statistical bureaus of various prefectural-level cities in northern Anhui Province

As shown in Table 4, from 2019 to 2023, the total number of patent applications in the six cities of northern Anhui increased from 17,500 to 23,480, with a cumulative growth of 34.2%. Overall, it presented an evolution pattern of "first rising then stabilizing and improving". By region, Fuyang consistently ranked first with over 5,200 applications, but reached a peak of 6,500 in 2021 and then dropped to 5,211 in 2023. Suzhou demonstrated the strongest growth resilience, with the number of patent applications rising from 2,800 to 4,752, achieving a cumulative increase of 69.7%, and rising from the third place to the second place. It is worth noting that the growth rates of cities with lower bases were the most significant. Huainan and Huaibei increased from 1,500 and 1,200 respectively to 3,000, doubling their numbers. The ratio between the highest and lowest among the six cities narrowed from 4.33 times in 2019 to 1.74 times in 2023, indicating that the innovation pattern in the northern Anhui region is evolving from "leadership by Fuyang and Bengbu" to "multi-polar coordination and convergence of gaps", and regional innovation balance has significantly improved.

2.2.2 The number of high-tech enterprises

High-tech enterprises are an important indicator for measuring the innovation level of a region, and enterprises are the main force in the transformation of innovation. As shown in Table 5, from 2019 to 2024, the total number of high-tech enterprises in the six cities of northern Anhui Province increased from 761 to 1,723, with an average annual growth rate of 17.8%. The cultivation of regional high-tech enterprises achieved rapid expansion. By city, Bengbu had the largest base of high-tech enterprises, reaching 487 in 2024, ranking 3rd in the province. Fuyang had 356, ranking 2nd in the northern part of Anhui and 5th in the province. Bozhou, Suzhou, and Huaibei had an average annual growth rate of over 20%, with strong growth momentum. Huainan and Huaibei had relatively low absolute numbers of enterprises and relatively lower rankings in the province, but still maintained an average annual growth rate of 16.9% to 20.0%, reflecting that the cultivation of high-tech enterprises in all parts of northern Anhui achieved significant results. However, the gap in the existing scale among cities still exists objectively, and there is a relatively obvious differentiation in the volume of innovation carriers between leading cities and latecomers.

Table 5 Number of High-tech Enterprises (in Units of Thousands)

City	2019	2021	2023	2024	average growth rate per annum	Provincial ranking (2024)
Fuyang	158	217	298	356	17.6%	5
Bozhou	87	126	184	225	21.0%	9
Suzhou	102	148	210	258	20.4%	7
Bengbu	243	325	412	487	14.9%	3
Huainan	95	132	175	208	16.9%	10
Huaibei	76	108	153	189	20.0%	12
Total	761	1,056	1,432	1,723	17.8%	

Data source: "High-tech Enterprise Statistical Yearbook" of the Anhui Provincial Science and Technology Department and "Science and Technology Innovation Development Reports" of each city.

As shown in Table 6, the levels of innovation investment, output and technology transfer in the six cities of northern Anhui Province exhibit significant urban heterogeneity. Bengbu leads the region in all indicators, with an R&D investment ratio of 3.4%. The average number of invention patents of enterprises, the amount of enterprise technology contracts, and the rate of innovation technology transfer are 5.8, 4.12 million yuan and 72% respectively, significantly higher than those of other cities in northern Anhui. Fuyang and Huaibei follow closely, with R&D investment ratios of

2.8% and 2.9% respectively. The number of invention patents per enterprise is 4.2 and 4.0 respectively, and the innovation technology transfer rate is over 60%. Suzhou, Bozhou and Huainan have relatively weak innovation efficiency overall. Among them, the R&D investment ratio of Huainan City is 2.6%, the number of invention patents per enterprise is 3.3, the amount of technology contracts is 2.25 million yuan, and the innovation technology transfer rate is only 55%, the lowest level in the region. Overall, there are gradient gaps in innovation resource allocation, enterprise innovation output and technology transfer among the various cities in northern Anhui. Most cities still have considerable room for improvement.

Table 6 Core Indicators of Innovation Effectiveness

City	Research and Development Investment Ratio (%)	Patent Invention (Number)	Technical Contract Amount (in ten thousand yuan)	Innovation achievement conversion rate (%)
Fuyang	2.8	4.2	295	63%
Bozhou	2.5	3.6	240	58%
Suzhou	2.7	3.9	279	61%
Bengbu	3.4	5.8	412	72%
Huainan	2.6	3.3	225	55%
Huaibei	2.9	4.0	243	60%

Data source: "Statistical Yearbook of High-tech Enterprises" by the Anhui Provincial Science and Technology Department, and "Science and Technology Innovation Development Reports" of each city.

2.2.3 Transaction volume of technology contracts

As shown in Table 7, from 2019 to 2024, the total transaction volume of technology contracts in the six cities of northern Anhui Province increased from 1.46 billion yuan to 4.77 billion yuan, with an average annual growth rate of 26.80%. The regional technology transaction market scale achieved rapid expansion. By city, Bengbu consistently maintained the leading total volume, with the transaction volume reaching 1.42 billion yuan in 2024, being the core carrier of technology transformation in northern Anhui. Fuyang followed closely with a transaction volume of 1.05 billion yuan. From the perspective of growth rate, the average annual growth rates of Huaibei, Bozhou, and Suzhou were 30.80%, 29.10%, and 28.00% respectively. The technology transaction growth momentum of the late-developing cities was strong, although their absolute transaction volume was still lower than that of Bengbu and Fuyang, but their growth momentum was outstanding. Overall, the transaction volume of technology contracts in each city of northern Anhui has steadily increased over the past several years. Although there is still a gap in absolute volume among cities, all cities maintained an average annual growth rate of over 24%, reflecting the overall continuous release of the marketization transformation vitality of scientific and technological achievements in northern Anhui.

Table 7 Data on the Transaction Volume of Technology Contracts in Northern Anhui (2019-2024) (100 Million Yuan)

City	2019	2020	2021	2022	2023	2024	average growth rate per annum
Fuyang	3.2	4.1	5.6	6.8	8.3	10.5	26.80%
Bozhou	1.5	2	2.7	3.5	4.2	5.4	29.10%
Suzhou	2.1	2.8	3.9	4.7	5.9	7.2	28.00%
Bengbu	4.8	6	7.5	9.1	11.4	14.2	24.20%
Huainan	1.8	2.3	3	3.8	4.6	5.8	26.40%
Huaibei	1.2	1.6	2.2	2.9	3.7	4.6	30.80%
Total	14.6	18.8	24.9	30.8	38.1	47.7	26.80%

Data source: Public data from the Anhui Provincial Bureau of Statistics and the statistical bureaus of each city.

3 THE IMPACT MECHANISM OF RURAL E-COMMERCE IN NORTHERN ANHUI ON REGIONAL INNOVATION EFFICIENCY

3.1 Direct Impact Mechanism

3.1.1 Rural e-commerce expands market space and stimulates innovation vitality

Rural e-commerce breaks the time and space limitations of traditional trade, allowing agricultural products and characteristic handicrafts from Northern Anhui to break through regional constraints and effectively expand the market space. However, market demand is developing towards a trend of diversification and individualization. In the face of an increasingly competitive market environment, enterprises and farmers must continuously innovate products and services in order to stand out. As competition intensifies, enterprises are also encouraged to continuously increase research and development investment and enhance their own innovation capabilities. On e-commerce platforms, there are many homogeneous products. Enterprises can only attract more consumers and gain a higher market share by continuously innovating product quality and service levels. This also prompts enterprises to actively introduce advanced production technologies and management experience, and strengthen technological cooperation with universities and research institutions for technological innovation and product development. Some e-commerce enterprises collaborate with universities to conduct research and development on agricultural product preservation technologies, jointly developing

new agricultural product preservation technologies, extending the preservation period of agricultural products and improving their quality and market competitiveness. Online sales channels expand and increase the return on investment of innovation. In terms of service innovation, some e-commerce enterprises also introduce personalized packaging services, customizing different styles of packaging according to consumer needs, meeting different scenarios such as gift-giving on holidays and family use. At the same time, they also focus on the innovation of after-sales services, establishing a complete customer feedback mechanism, promptly handling consumer complaints and suggestions, and improving consumer satisfaction and loyalty.

3.1.2 Optimize resource allocation and reduce innovation costs

The development of rural e-commerce can integrate various resources in rural areas, enabling them to be optimally allocated, thereby enhancing the efficiency of innovation. In terms of human resources, the development of rural e-commerce can attract migrant workers, bringing advanced technologies and management experience back to rural areas, providing new vitality for rural innovation, and at the same time, the development of rural e-commerce can also provide employment opportunities for local farmers, helping them find jobs at home and increasing their income levels. In terms of material resources, the development of rural e-commerce promotes the establishment and improvement of rural logistics and warehousing infrastructure, improving the efficiency of rural logistics distribution and reducing the logistics costs of rural e-commerce. Rural e-commerce enterprises integrate the material and warehousing resources in rural areas to establish centralized warehousing centers, achieving the sharing and utilization of warehousing resources; rural e-commerce enterprises also cooperate with rural logistics enterprises to optimize logistics distribution routes, improve logistics distribution efficiency, and reduce logistics costs, enabling e-commerce enterprises to more efficiently allocate materials and providing stronger material support for innovation. From the perspective of financial resources, rural e-commerce has also received more capital investment and has the funds for innovation and entrepreneurship. At the same time, the government attaches great importance to the development of rural e-commerce and encourages e-commerce enterprises and farmers to engage in e-commerce entrepreneurship through fiscal subsidies and tax incentives. Financial institutions have also increased credit support for rural e-commerce enterprises, enabling e-commerce to obtain the funding sources for development. Rural e-commerce also utilizes technologies such as big data and cloud computing to achieve information sharing and resource optimization. E-commerce platforms accumulate a large amount of consumer data, and enterprises can analyze the consumer data to identify consumers' needs and preferences, and carry out product research and innovation in a targeted manner. Through the analysis of consumer purchase records and evaluation data, enterprises can understand consumers' satisfaction with products and suggestions for product improvements, promptly adjust product strategies, and improve product quality and competitiveness. Big data technology can also help enterprises optimize the supply chain, improve the efficiency and agility of the supply chain, and reduce operating costs.

3.2 Indirect Impact Mechanism

3.2.1 Industrial agglomeration and collaborative innovation efficiency

The development of rural e-commerce in northern Anhui Province has promoted industrial agglomeration, providing conditions for enhancing regional innovation efficiency. As the transaction scale of rural e-commerce gradually expands, various related industries such as e-commerce enterprises, logistics enterprises, and agricultural product processing enterprises have gathered in northern Anhui. Logistics enterprises and e-commerce enterprises collaborate for innovative activities, which also improves the efficiency and quality of logistics distribution. Logistics enterprises optimize the selection of logistics distribution routes and distribution methods based on the business characteristics of e-commerce enterprises and their demands, providing efficient and rapid distribution services. Logistics enterprises also utilize shared technologies, talents, equipment, etc., to achieve rational resource allocation and enhance the efficiency of enterprise innovation. Enterprises within the agglomeration area jointly build specialized public service platforms such as research and development centers and testing centers, sharing advanced technologies and research resources, and reducing the cost of enterprise innovation. Industrial agglomeration also enhances the spillover effect of knowledge and technology, and accelerates the diffusion and dissemination of innovation. The personnel mobility within the agglomeration area is high, and technologies and knowledge can easily flow rapidly within the industry. The innovation achievements of one enterprise can often be quickly absorbed and imitated by other enterprises, promoting the innovative development of the industry.

3.2.2 Improvement of the innovation environment and attraction of innovative talents

The development of rural e-commerce in Anhui North has improved the innovation environment. The growth of e-commerce has led to the continuous improvement of various infrastructure in rural areas, including network communication, logistics distribution, and financial services. In terms of network communication, with the development of rural e-commerce, Anhui North has continuously increased its investment in rural network infrastructure, achieving full coverage of rural networks and continuously improving network speed and stability, creating favorable network conditions for e-commerce to carry out various businesses and innovate. The demand for rural e-commerce has led logistics distribution enterprises to establish more rural distribution outlets, optimizing logistics distribution routes and improving logistics distribution efficiency. Anhui North has combined postal delivery and logistics distribution, establishing a three-level logistics distribution system at the county, town, and village levels, breaking through the "last mile" of logistics distribution. Rural e-commerce has provided a broad development platform for innovative talents, offering many entrepreneurial opportunities and a wide range of possibilities. More and more college students with

innovative dreams and young people returning to their hometowns are increasingly participating in the rural e-commerce sector. For example, Mengcheng County, using the national e-commerce integration into rural areas comprehensive demonstration project as a carrier, has actively explored the "e-commerce + talent" development model in e-commerce talent cultivation, attracting talents to join the rural e-commerce team. As of 2023, Mengcheng County has built 100 village-level integration outlets, gathered a large number of high-quality e-commerce leaders, established an e-commerce talent reserve pool, and accumulated 4,000 talents. Innovative talents bring new ideas such as technology, management, and business concepts, injecting new impetus into the development of rural e-commerce and further enhancing regional innovation efficiency.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Research Conclusions

(1) The overall scale of rural e-commerce in northern Anhui has steadily increased, forming distinct characteristic products and brands, and establishing a multi-party participation innovation model; (2) The number of patent applications and high-tech enterprises in northern Anhui has shown a trend of "initial increase followed by stabilization and improvement", with the level of R&D investment continuously rising, and the transaction volume of regional technology contracts growing rapidly; (3) The development of rural e-commerce in northern Anhui has expanded market space, optimized resource allocation, stimulated innovation vitality, and reduced innovation costs, directly improving regional innovation efficiency; (4) The development of rural e-commerce in northern Anhui has indirectly promoted the improvement of regional innovation efficiency through industrial agglomeration and the attraction of innovative talents.

4.2 Policy Recommendations

4.2.1 Strengthen policy support and guidance

The government should attach importance to the development of rural e-commerce in Anhui North region and incorporate it into the regional economic development plan. Develop long-term development plans and specific measures to ensure that the policies can be truly implemented. Increase the investment in fiscal funds and establish a rural e-commerce development fund, which will be mainly used for rural e-commerce infrastructure construction, talent cultivation, brand building, and technological innovation. Provide construction subsidies for newly established or renovated e-commerce public service centers and logistics distribution centers, and offer financial support to enterprises that carry out e-commerce training, brand building, and other activities. Establish a rural e-commerce entrepreneurship fund, provide entrepreneurship subsidies and loan interest subsidies to young people and college students who return to their hometowns to start businesses, and encourage them to engage in rural e-commerce. The government should strengthen the management of the rural e-commerce market, establish a market supervision system, maintain market order, and protect consumers' rights and interests. Strengthen the supervision of e-commerce platforms, and e-commerce platforms should strengthen the review and management of merchants entering the platform, supervise the merchants, and strengthen the supervision of product quality and service quality. Strengthen the supervision of agricultural products, establish an agricultural product quality traceability system, enabling the entire process from production to sales of agricultural products to be traced, so that consumers can buy with confidence and eat with confidence.

4.2.2 Improve the infrastructure construction of rural e-commerce

Increase investment to fund the construction of network communication infrastructure in rural areas of Anhui Province's northern regions. Promote the coverage of 5G networks, fiber-optic broadband and other infrastructure in rural areas. Establish a special fund for network construction to support communication network operators in rural areas to carry out fiber communication and base station construction, etc., to enhance the network speed and stability. For remote mountainous areas with poor communication signals, use satellite communication methods to ensure the coverage of communication signals. Strengthen the construction of rural logistics distribution networks. Gather postal and express logistics resources, establish a three-level logistics distribution system at county, town and village levels, and break through the "last mile" of distribution. Strengthen the informatization construction in rural areas, cultivate farmers' awareness and information literacy of informatization, conduct informatization training, and organize professional technicians to go to rural areas to train farmers' informatization operation skills. Establish an agricultural product e-commerce platform with characteristics of Anhui Province's northern region. Integrate agricultural product resources of Anhui Province's northern region, establish a unified agricultural product e-commerce platform, and provide services such as agricultural product display, sales, and logistics distribution.

4.2.3 Cultivating and attracting innovative talents

Cooperate with universities and vocational colleges to establish rural e-commerce majors, providing targeted education. Cultivate practical e-commerce talents. Launch training programs, catering to the different e-commerce training needs of rural residents, returning entrepreneurs, etc., and offer targeted courses to cultivate practical e-commerce talents. At the same time, implement housing subsidies, entrepreneurship support funds, and children's education subsidies, etc., to attract e-commerce talents from outside the region to work and start businesses in the rural areas of northern Anhui.

4.2.4 Promote the integrated development of rural e-commerce and industries

It is necessary to continuously advance the in-depth integration of rural e-commerce and rural industries. Based on the characteristic agricultural resources of Northern Anhui, we shall consolidate the foundation of characteristic industries, improve the standardization and branding of agricultural products, and shore up weaknesses in county-level infrastructure such as cold-chain warehousing and logistics distribution. We shall vigorously foster local e-commerce operators, develop new business forms including live-streaming e-commerce and contract farming, and expand integrated paths of “e-commerce + crop-livestock farming” and “e-commerce + cultural-tourism”. Efforts should be intensified to cultivate e-commerce talents, build an interest-linkage mechanism of “platform + enterprises + cooperatives + farmers”, and improve systems for quality supervision and policy support. Market demands from e-commerce shall be leveraged to empower the production end in reverse, smooth the whole industrial chain for upward circulation of agricultural products, enable farmers to share the added-value benefits of industries, and realize the quality improvement and efficiency enhancement of rural industries driven by digital technologies.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ETHICAL STATEMENT

This study only adopts publicly released statistical data and anonymous questionnaire survey data without collecting sensitive personal privacy information of individuals. No human subjects, clinical trials or animal experiments are involved in this research, so ethical approval and informed consent are not required.

REFERENCES

- [1] Cooke P. Regional innovation systems: competitive regulation in the new Europe. *Geoforum*, 1992, 23(3): 365-382.
- [2] Etzkowitz H, Leydesdorff L. The dynamics of innovation: from National Systems and “Mode 2” to a Triple Helix of university–industry–government relations. *Research Policy*, 2000, 29(2): 109-123.
- [3] Boschma R. Proximity and innovation: a critical assessment. *Regional Studies*, 2005, 39(1): 61-74.
- [4] An B, Xu P, Liu L, et al. Assessing green innovation efficiency and spatial characteristics of China’s high tech industry based on the three stage undesirable SBM model. *Scientific Reports*, 2025, 15(1): 29917. DOI: 10.1038/S41598-025-16189-W.
- [5] Xia K, Guo J, Han Z, et al. Analysis of the scientific and technological innovation efficiency and regional differences of the land–sea coordination in China’s coastal areas. *Ocean and Coastal Management*, 2019, 172: 157-165. DOI: 10.1016/j.ocecoaman.2019.01.025.
- [6] Bai J. On Regional Innovation Efficiency: Evidence from Panel Data of China’s Different Provinces. *Regional Studies*, 2013, 47(5): 773-788. DOI: 10.1080/00343404.2011.591784.
- [7] Wang S, Fan J, Zhao D, et al. Regional innovation environment and innovation efficiency: the Chinese case. *Technology Analysis & Strategic Management*, 2016, 28(4): 396-410. DOI: 10.1080/09537325.2015.1095291.
- [8] Xu K, Bossink B, Chen Q. Efficiency Evaluation of Regional Sustainable Innovation in China: A Slack-Based Measure (SBM) Model with Undesirable Outputs. *Sustainability*, 2020, 12(1): 31. DOI: 10.3390/su12010031.
- [9] Cao X, Chen B, Si Y, et al. Spatio-temporal evolution and mechanism of regional innovation efficiency: Evidence from Yangtze River Delta Urban Agglomeration of China. *PLOS ONE*, 2021, 16(7): e0253598. DOI: 10.1371/JOURNAL.PONE.0253598.
- [10] Liang L, Xu K. Convergence analysis of regional sustainable innovation efficiency in China. *Environment, Development and Sustainability*, 2022, 25(3): 2758-2776. DOI: 10.1007/S10668-022-02159-Z.
- [11] Zhang Z, Cheng Y, Zhang J. Spatial spillover and threshold effects of digital economy on green innovation efficiency–based on provincial level data in China. *Environment, Development and Sustainability*, 2023, 27(3): 1-23. DOI: 10.1007/S10668-023-04164-2.
- [12] Deng Q, Long Y, Nie R. Exploring pathways to regional green technology innovation efficiency: drivers, barriers, and insights from configurational pathways analysis in China. *Environment, Development and Sustainability*, 2025: 1-39. DOI: 10.1007/S10668-025-06962-2.
- [13] Zhu Y, Jing H, Hu Y. Impact of regional digital maturity on green innovation efficiency: the moderating effect of financial development. *Kybernetes*, 2026, 55(9): 4165-4187. DOI: 10.1108/K-10-2024-2868.
- [14] Liu L, Wang Y. How Does the Agglomeration of High-End Talent Affect Regional Innovation Efficiency? *Sustainability*, 2026, 18(16): 8553. DOI: 10.3390/SU18168553.