

Technology Empowerment, Industrial Integration and Spatial Reconstruction: The Theoretical Logic and Practice of Low-Altitude Economy Empowering Rural Revitalization

-- A Case Study of Shandong Province

Minghui Li^{1,*}, Jiayi Huang²

¹ School of Management, Shandong University of Technology, Zibo, China

² School of Information and Electronic Engineering, Shandong Technology and Business University, Yantai, China

* Corresponding author: (Email: mhlizb@163.com)

Abstract: The low-altitude economy is accelerating its penetration from urban to rural areas, becoming an emerging force driving rural revitalization. This paper constructs a three-dimensional analytical framework of “technology empowerment–industrial integration–spatial reconstruction” to explain the theoretical logic of the low-altitude economy empowering rural revitalization. Taking Shandong Province as a typical case, this paper systematically reviews its agricultural low-altitude economy development practices, analyzes the realistic bottlenecks from three dimensions—fragile innovation chain, homogenized application scenarios, and lagging institutional supply—and proposes promotion paths with scenario innovation as the driver, technological breakthroughs as the core, and institutional optimization as the guarantee, so as to provide a reference for the low-altitude economy to empower rural revitalization.

Keywords: Low-altitude economy; Rural revitalization; Technology empowerment; Industrial integration; Spatial reconstruction; Shandong Province.

1. Introduction

In 2024, the “low-altitude economy” was written into the Government Work Report for the first time, and the Third Plenary Session of the 20th Central Committee of the Communist Party of China further incorporated the development of general aviation and the low-altitude economy into the national strategic deployment. According to estimates, the national low-altitude economy industrial scale reached 670.25 billion yuan in 2024 and grew to approximately 1.5 trillion yuan in 2025, and is expected to exceed 3.5 trillion yuan by 2035 according to the forecast of the Civil Aviation Administration of China. At the same time, the rural revitalization strategy is being comprehensively promoted. How to activate rural resources and reshape rural space with the help of emerging technological means has become a major proposition that urgently needs to be addressed.

Existing studies have carried out beneficial explorations from multiple perspectives. Hou Guanyu et al. analyzed the value logic of the low-altitude economy empowering rural revitalization from the perspective of the “five revitalizations” [1]; Chen Kee et al. studied the logical mechanisms and scenario construction [2]; Ma Yaoyan analyzed the mechanisms and promotion paths of the low-altitude economy empowering the development of new quality productive forces in agriculture [3]; Wang Shuhe analyzed the mechanisms, challenges, and response paths [4]; Song Yanping et al. studied the practice of the low-altitude economy empowering modern agriculture in Renqiu, Hebei [5]; Jia Zhenglin and Li Bo explored the value implications and practical obstacles of the low-altitude economy

empowering rural revitalization [6]; Ma Li and Bu Kaiyin studied the pathways to solve the challenges of the low-altitude economy empowering rural revitalization [7]. The above studies have laid an important foundation for this research from the perspectives of theoretical mechanisms, value logic, and practical paths, but most of them remain at the level of theoretical interpretation or macro-analysis, with insufficient in-depth diagnosis of specific regions. This paper takes Shandong Province as a typical case, constructs a three-dimensional analytical framework, and analyzes the theoretical logic, realistic bottlenecks, and promotion paths of the low-altitude economy empowering rural revitalization.

2. Analytical Framework

The empowerment of rural revitalization by the low-altitude economy is not a simple technological “implantation,” but a multi-dimensional and systematic “embedding” process. Its essence is to transform the underutilized low-altitude airspace in rural areas into new development space through low-altitude technology, achieving “spatial fix” and value reconstruction [8]. Drawing on existing research, this paper constructs a three-dimensional framework of “technology empowerment–industrial integration–spatial reconstruction,” with the three dimensions corresponding respectively to the tool foundation, industrial carrier, and spatial effects of the low-altitude economy, jointly forming a complete logical chain [9].

2.1. Technology Empowerment

Technology empowerment is the foundational dimension. The low-altitude economy embeds technologies such as unmanned aerial vehicles (UAVs), low-altitude intelligent

networks, multi-spectral remote sensing, and AI recognition into the entire chain of agricultural production [10], constructing a “space-air-ground integrated” agricultural information perception network, transforming agricultural production from “experience dependence” to “data-driven,” and achieving the leap from “substitute tool” to “systemic embedding.”

2.2. Industrial Integration

Industrial integration is the core dimension. The empowerment of the low-altitude economy on rural industries runs through the entire chain of “production–processing–circulation–services” [11], giving rise to new forms of agricultural socialized services and promoting the transformation of rural industries from “selling raw materials” to “selling services,” “selling data,” and “selling experiences.”

2.3. Spatial Reconstruction

Spatial reconstruction is the expanding dimension. Low-altitude aircraft break through the limitations of ground road networks, achieving vertical expansion of physical space, network reconstruction of economic space, and relationship reshaping of social space, making rural areas no longer information islands or development depressions. From the perspective of spatial production theory, the essence of the low-altitude economy is to transform rural airspace from “natural space” into exploitable “economic space” and “social space” [12]. Spatial production theory reveals that space is not only a container for economic activities but also an important source of value creation—when low-altitude aircraft incorporate rural airspace into the production function, the previously idle airspace resources acquire economic attributes and become new space that can be developed and utilized. Its significance for spatial reconstruction lies in breaking through the geographical constraints of ground road networks through technological means, expanding rural space from a two-dimensional plane to a three-dimensional space, and alleviating the rigid constraints of “geographical isolation” on factor mobility in traditional development models. The three dimensions support each other and progress step by step, jointly forming a complete logical chain.

3. Practical Exploration in Shandong Province

Shandong Province has earnestly implemented the “Shandong Province Low-Altitude Economy High-Quality Development Three-Year Action Plan (2025–2027),” and the agricultural low-altitude economy has shown rapid development momentum.

3.1. Equipment Popularization and Large-Scale Operations

By the end of 2025, the province’s plant protection UAV fleet exceeded 18,000 units, covering all counties (cities and districts), with equipment upgrading toward larger load capacity and greater intelligence. The province’s annual agricultural low-altitude operation area reached 170 million mu·times.

3.2. Typological Generation of Typical Scenarios

Based on the resource endowments and industrial characteristics of different regions, six major models have

emerged: platform-based unified pest control (Jinan, Laixi), smart agriculture in saline-alkali land (Dongying), characteristic applications in mountainous and hilly areas (Zibo), logistics integration for characteristic industries (Qingdao, Yantai), industrial ecological cultivation (Jining), and precision operation demonstration (Zaozhuang, Heze). Linyi, Binzhou and other areas are exploring new scenarios such as online crowdsourcing and animal husbandry management.

3.3. Initial Formation of the Industrial Ecosystem

The province has initially cultivated an industrial pattern of “equipment sales + operation services + maintenance training,” actively cultivating specialized service organizations and certified pilots. The completion of the Jining Low-Altitude Economy Industrial Park marks the extension from “application-oriented” to “full industrial chain.”

4. Multi-Dimensional Dilemmas

4.1. Dilemma of the Technology Empowerment Dimension: Fragile Innovation Chain

The high-end supply of core components such as flight control systems, high-energy-density batteries, and multi-spectral sensors mainly relies on enterprises from other provinces. Although there are some local deployments within the province, the overall R&D and manufacturing capacity is relatively insufficient, and the technological foundation remains unstable.

4.2. Dilemma of the Industrial Integration Dimension: Homogenized Scenarios

Low-altitude operations are still mainly concentrated in the pest and disease control sector, with a relatively high proportion, while high-value-added scenarios such as precision variable fertilization, agricultural remote sensing monitoring, and agricultural product transportation—although explored—have not yet formed large-scale applications, and generally remain at the tool level of “replacing manual labor.”

4.3. Dilemma of the Spatial Reconstruction Dimension: Lagging Institutional Supply

Spatial reconstruction depends not only on physical infrastructure but also on the synchronous construction of institutional infrastructure. The current supply of soft institutions such as airspace management systems, data interface standards, and cross-regional coordination mechanisms is relatively lagging, and the “institutional foundation” of spatial reconstruction has failed to keep pace. Standardized take-off and landing sites and battery charging and swapping facilities are still insufficient; operational technical standards, safety operation specifications, and data interface standards need to be improved; the special support policy system is still imperfect. These institutional shortcomings overlap at the physical space level (insufficient infrastructure supply) and the social space level (lack of rules and standards), constraining the large-scale expansion of the “three-dimensional connectivity” function of the low-altitude economy in rural scenarios.

5. Experience Reference

5.1. Domestic Practices

Jiangxi Nankang takes “demand-driven” as its logical starting point, with UAV logistics opening up the channel for agricultural products from remote mountain villages to reach the market. Zhejiang’s “rural low-altitude +” model incorporates the low-altitude economy into the collective economy framework, lowering the threshold for smallholder participation [13]. Shenzhen relies on DJI Innovations to build a full-industry-chain ecosystem, providing experience for technology diffusion [14].

5.2. International Experiences

Japan started from scenarios such as island logistics and medical emergency, relaxing regulations in specific areas through “special zones” and “sandbox” models, achieving reverse adaptation of technology and institutions. The United States, with NASA and universities at its core, publicly releases cutting-edge research results and software tools to society, lowering the entry barrier for the industry.

5.3. Core Implications

A comprehensive review of the above domestic and international practices reveals that three key factors are essential for the effective promotion of the low-altitude economy empowering rural revitalization. First, demand orientation—taking the actual needs of rural areas as the logical starting point, rather than technological supply as the starting point, and deriving technological solutions backward from real pain points such as plant protection, logistics, and monitoring, avoiding the “use for use’s sake” technology piling. Second, institutional adaptation—the promotion and application of low-altitude technology in rural areas requires supporting institutional supply. Institutional frameworks such as airspace management, flight approval, safety supervision, and data standards should match the low-risk and decentralized characteristics of rural scenarios, reducing institutional transaction costs. Third, benefit sharing—the sustainable development of the rural low-altitude economy requires the construction of a diversified benefit linkage mechanism, enabling technological dividends to benefit farmers, village collectives, and business entities, and forming a “low-altitude economy + collective economy” integrated development pattern through collective economic organizations as a unified interface for external technical services, ensuring benefit sharing and risk sharing.

6. Promotion Paths

Based on the systematic diagnosis of the three dilemmas under the three-dimensional framework and the three core implications distilled from domestic and international practices—“demand orientation, institutional adaptation, and benefit sharing”—this paper proposes the following promotion paths from the three dimensions of “technology empowerment–industrial integration–spatial reconstruction.” Among them, scenario innovation responds to the dilemma of scenario homogenization in the “industrial integration” dimension, with its core principle being “demand orientation”—expanding application scenarios from the real needs of rural areas; technological breakthroughs respond to the fragile innovation chain in the “technology empowerment” dimension; institutional optimization responds to the lagging

institutional supply in the “spatial reconstruction” dimension, while embodying the implications of “institutional adaptation” and “benefit sharing,” building an institutional framework that matches rural characteristics and enabling technological dividends to benefit multiple stakeholders.

6.1. Scenario Innovation as the Driver

Deepen food production scenarios and promote standardized unified pest control; expand characteristic industrial scenarios and cultivate differentiated applications; explore new forms of agricultural, cultural, and tourism integration. All regions can choose scenario directions according to their local resource endowments and conditions.

6.2. Technological Breakthroughs as the Core

Establish special science and technology programs focusing on key technological areas such as long-endurance batteries and intelligent flight control algorithms; enhance complete machine manufacturing capacity; build innovation platforms and shared pilot bases to reduce innovation costs.

6.3. Institutional Optimization as the Guarantee

Improve the planning of infrastructure such as take-off and landing sites and battery charging and swapping stations; establish “green channels” for low-altitude operations; improve technical standards and data interface standards; innovate risk diversification mechanisms; and draw on Zhejiang’s “rural low-altitude +” experience to explore a “low-altitude economy + collective economy” integrated development model and improve the benefit-sharing mechanism linking agriculture with farmers. All regions can advance in steps according to their own development stages and institutional conditions.

7. Conclusions

This paper constructs a three-dimensional analytical framework of “technology empowerment–industrial integration–spatial reconstruction,” systematically explains the theoretical logic of the low-altitude economy empowering rural revitalization, and takes Shandong Province as a typical case for analysis, hoping to provide a reference sample for similar regions across the country. This study draws the following main conclusions:

First, the empowerment of rural revitalization by the low-altitude economy is not a simple technological “implantation,” but rather, through the synergistic effects of three mechanisms—technology empowerment, industrial integration, and spatial reconstruction—achieves the fundamental transformation from “substitute tool” to “systemic embedding,” from “single operation” to “full-chain reconstruction,” and from “geographical isolation” to “three-dimensional connectivity.”

Second, Shandong Province has achieved remarkable results in empowering rural revitalization through the low-altitude economy—the province’s plant protection UAV fleet exceeds 18,000 units, the annual operation area reaches 170 million mu·times, and six major types of characteristic application scenarios have emerged. However, it still faces three structural dilemmas: a fragile innovation chain, homogenized application scenarios, and lagging institutional supply, which constrain the full release of the empowerment effect and hinder the process of the low-altitude economy

empowering rural revitalization from “point breakthroughs” to “area-wide momentum.”

Third, to solve the above dilemmas, coordinated efforts are needed in three dimensions: scenario innovation, technological breakthroughs, and institutional optimization. Scenario innovation responds to “demand orientation,” expanding diversified application scenarios from the real needs of rural areas; technological breakthroughs respond to the fragile innovation chain, enhancing the independent supply capacity of core components and the level of complete machine manufacturing; institutional optimization responds to “institutional adaptation” and “benefit sharing,” on the one hand improving the planning of infrastructure such as take-off and landing sites and battery charging and swapping stations and airspace management systems to build an institutional framework that matches rural characteristics, and on the other hand drawing on Zhejiang’s “rural low-altitude +” experience to explore a “low-altitude economy + collective economy” integrated development model and improve the benefit-sharing mechanism linking agriculture with farmers, so that technological dividends benefit multiple stakeholders.

Acknowledgements

The authors gratefully acknowledge the financial support from the Key R&D Program (Soft Science Project) of Shandong Province, China, for the project “Research on the Path of Sci-Tech Innovation and Policy for Low-Altitude Economy in Shandong Province” (Grant No. 2025RZB0204), and project “Research on the Mode and Mechanism of Collaborative Innovation of Advanced Manufacturing Clusters to Build a Self-Controlled Industrial Chain” (ZR2022MG030) supported by Shandong Provincial Natural Science Foundation.

References

- [1] Hou, G., & Yu, H. (2025). The “new blue ocean” beneath the sky: Empowering comprehensive rural revitalization through the low-altitude economy. *Hunan Social Sciences*, (3), 51–57. (In Chinese)
- [2] Chen, K., & Song, C. (2025). Research on the logical mechanism and scenario construction of low-altitude economy empowering the development of new quality productive forces in agriculture. *Journal of Chengdu University of Technology (Social Sciences Edition)*, 33(5), 45–56. (In Chinese)
- [3] Ma, Y. (2026). The mechanism of action, realistic bottlenecks, and promotion paths of low-altitude economy empowering the development of new quality productive forces in agriculture. *Journal of Kunming University of Science and Technology (Social Sciences Edition)*, 26(3), 100–110. (In Chinese)
- [4] Wang, S. (2025). Low-altitude economy empowering rural revitalization: Mechanisms, challenges, and response paths. *Industrial Innovation Research*, (15), 127–129. (In Chinese)
- [5] Song, Y., Zheng, Q., & Liu, C. (2025). Paths and countermeasures for low-altitude economy empowering modern agriculture in Renqiu, Hebei. *Agricultural Engineering Technology*, 45(32), 88–89. (In Chinese)
- [6] Jia, Z., & Li, B. (2025). Low-altitude economy empowering rural revitalization: Value implications, realistic obstacles, and optimization paths. *Xinjiang Agricultural Reclamation Economy*, (8), 48–59. (In Chinese)
- [7] Ma, L., & Bu, K. (2026). Theoretical logic, realistic dilemmas, and solution paths of low-altitude economy empowering rural revitalization. *Journal of Chongqing University of Science and Technology (Social Sciences Edition)*, (1), 90–101. (In Chinese)
- [8] Zhang, Q., & Zhang, H. (2026). The underlying logic and implementation paths for the low-altitude economy to promote rural revitalization. *Economy and Management*, 40(2), 1–9. (In Chinese)
- [9] Xu, X., Li, B., & Yu, Q. (2025). Theoretical mechanisms, realistic challenges, and practical paths of low-altitude economy empowering rural revitalization. *Journal of National Forestry and Grassland Administration Management Cadre College*, 24(3), 59–67. (In Chinese)
- [10] He, Y., Wang, Y., & He, L. (2025). Current status and prospects of low-altitude economy policies and technologies in agricultural and rural areas. *Transactions of the Chinese Society of Agricultural Engineering*, 41(8), 1–16. (In Chinese)
- [11] Li, Z., Tan, J., & Huang, X. (2025). The internal logic and practical approach of low-altitude economy empowering rural revitalization. *Journal of Xichang University (Social Sciences Edition)*, 37(4), 31–39. (In Chinese)
- [12] Wan, H., & Zhu, Y. (2026). From embedding to symbiosis: The practical turn and progressive mechanism of low-altitude economy driving endogenous rural development. *Journal of Northwest Minzu University (Philosophy and Social Sciences Edition)*, (3), 65–75. (In Chinese)
- [13] Chen, H., & Zhu, Y. (2025). Ningbo experience and countermeasure suggestions for low-altitude economy empowering rural common prosperity. *Ningbo Economy (Sanjiang Forum)*, (11), 31–34. (In Chinese)
- [14] Zhu, A., Wang, H., & Li, W. (2024). Realization mechanism of modular-driven core enterprise innovation ecosystem evolution: A case study of DJI. *Journal of Shenyang University of Technology (Social Sciences Edition)*, 17(4), 400–410. (In Chinese)