Research on the Relationship between Urban Development and the Private Economy in Yunnan under the Context of Low-Altitude Economy

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Abstract. As a strategic emerging economic form in China, the low-altitude economy serves as a quintessential representative of new quality productivity. Specifically, it represents a comprehensive economic model anchored in the general aviation industry, which radiates and facilitates the coordinated development of various sectors, including low-altitude travel, flight entertainment, and aviation experiences. This emerging economy is gradually evolving into a new engine for promoting economic growth across diverse regions. This study elucidates the transmission pathways and mechanisms through which the low-altitude economy influences regional development by constructing a three-dimensional analytical framework encompassing 'factor integration, spatial reconstruction, and institutional innovation.' Considering Yunnan's unique three-dimensional geographical characteristics and its advantageous border location, this research finds that the integration of low-altitude elements effectively transcends the limitations of traditional transportation, engenders new industrial spatial configurations, and fosters the cross-regional flow of production factors through shared infrastructure. This research analyzes the pivotal role of private enterprises in fostering new business formats, aiming to balance regional advantages and challenges through the diffusion of technological innovation and the iteration of business models. The study seeks to achieve multi-party collaboration, resource sharing, and the assurance of safety standards in advanced low-altitude technology, driven by scientific and technological innovation. Anchored in the objective of reducing costs and enhancing efficiency, and guided by policies that promote sustainable development, it aspires to establish distinctive industrial chains such as 'low-altitude + tourism' and 'low-altitude + logistics.' The research indicates that optimizing the institutional environment and innovating market access mechanisms can effectively invigorate the vitality of private capital, constructing a collaborative

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development model that is government-guided and enterprise-led. By cultivating industrial ecosystems and co-building new infrastructure, this study emphasizes the achievement of high-quality development amid urban and private economic growth in Yunnan. Furthermore, it proposes differentiated policy design pathways and provides a theoretical foundation for empowering regional collaborative development strategies within the low-altitude economy.

Keywords: Low-altitude Economy; Yunnan Urban Uevelopment; New Quality Productivity; Private Economy

1 Introduction

Unlike traditional aviation economic models, the low-altitude economy represents an emerging economic form driven by a variety of aviation activities, including manned aircraft and drones. This economy is supported by specific airspace resources and propelled by innovative technological tools, which facilitate the integrated applications necessary for fostering deep convergence across various industries. In February 2021, the "National Comprehensive Three-Dimensional Transportation Network Planning Outline," issued by the Central Committee of the Communist Party of China and the State Council, explicitly proposed the development of the low-altitude economy, marking its formal inclusion in the national strategic development plan. Furthermore, the Central Economic Work Conference, held in December 2023, emphasized the necessity of developing new quality productive forces and actively cultivating strategic emerging industries, including the low-altitude economy, positioning them as vital strategic engines for high-quality economic development. Currently, provinces across the country are actively promoting the establishment of comprehensive demonstration zones for the low-altitude economy, thereby cultivating a 'new track' for the high-quality development of this sector. Among these initiatives, the drone industry has exhibited significant developmental advantages within China's low-altitude economic industrial framework. As of 2023, the number of registered drones in China has reached 1.267 million, reflecting a year-on-year increase of 32.2%. The total flight hours for the year amounted to 23.11 million, marking an increase of 11.8% compared to the previous year. There are nearly 2,000 drone design and manufacturing units and close to 20,000 operating enterprises nationwide. With the deepening of applications in fields such as emergency rescue, communication relay, and meteorological detection, the scope of drone applications has significantly broadened. Drones are now widely utilized in personal consumption, geographic mapping, aerial photography for film and television, and have achieved large-scale operations in the logistics sector. Since mid to late April 2024, multiple provinces and cities across the country have successively introduced specific implementation rules and supportive policies for the development of the low-altitude economy. The low-altitude economy has been officially incorporated into the government work reports by many local governments, with clear development goals and detailed implementation plans announced. Relevant research institutions predict that by 2025, the overall market size of China's low-altitude economy is expected to reach

859.17 billion yuan, becoming a significant growth driver and emerging strategic engine for promoting high-quality economic development [1].

Beneath the kilometer mark, opportunities abound. The low-altitude economy is poised for takeoff, with major cities racing to embrace a new pinnacle of industrial development. Since the beginning of this year, the low-altitude economy has rapidly gained public attention, standing at the forefront of development. From the central government to local authorities, a series of policy measures have been intensively introduced to support industrial development: The Third Plenary Session of the 20th CPC Central Committee explicitly proposed accelerating the development of the low-altitude economy; the Ministry of Industry and Information Technology, along with three other departments, issued the 'Implementation Plan for Innovation and Application of General Aviation Equipment (2024-2030),' focusing on building advanced manufacturing clusters in modern general aviation; and the Civil Aviation Administration of China, the National Development and Reform Commission, and other departments have successively released supportive measures in areas such as airport construction and urban digitalization, providing a solid institutional guarantee and strong policy impetus for the high-quality development of the low-altitude economy. As a plateau region, Yunnan possesses unique advantages in terms of its terrain, resources, and tourism culture, positioning it favorably for the development of a low-altitude economy characterized by regional strengths, talent, and diverse application scenarios. Accelerating the development of the low-altitude economy can not only promote the transformation and upgrading of industries such as tourism, logistics, and agriculture but also inject new vitality into regional economic development. In terms of aviation resource development and the enhancement of factor advantages, Yunnan aims to improve the efficiency of capital allocation, strengthen investment attraction, and create varied application scenarios. By the end of 2023, Yunnan Province had established 775 drone enterprises and 21 general aviation enterprises, with the province's general aviation flight operations exceeding 9,000 hours. The volume of flight operations in power operations, aerial inspections, weather modification, aerial forest protection, and skydiving all ranked within the top eight nationwide. Innovatively launching emerging formats such as "drone + tourism" and "drone + logistics" aims to fully develop aviation resources. Additionally, leveraging institutional elements serves to drive industrial agglomeration and secure a competitive advantage in low-altitude aircraft manufacturing technology. For instance, in Mile City, the Yunnan Low-altitude Economic Industrial Park is being developed by capitalizing on its comprehensive general airport facilities and advanced technological capabilities. This initiative seeks to establish an industrial cluster for general aviation and drone research and development (R&D) as well as manufacturing, thereby extending the aircraft manufacturing industry chain and fostering industrial integration and development. Efforts are underway to position Mile City as the "pioneer" and "technology leader" in advancing Yunnan's low-altitude economy.

In July 2024, the Kunming Municipal Government issued the "Implementation Opinions on Promoting the Development of Low-Altitude Economy in Kunming," which aims to establish the "three networks" of facilities, air routes, and services within the main urban area. The plan includes completing the planning of non-controlled airspace across the main urban area, constructing a safety supervision and service platform

for low-altitude aircraft, and establishing a flight service support system. The objective is to achieve a low-altitude economy scale of 30 billion yuan within three years. However, the development of the low-altitude economy in Yunnan Province faces several practical challenges: first, the supply of labor and technological resources is insufficient; second, institutional frameworks are not sufficiently comprehensive; third, the marketization process is slow, and the inefficient allocation of capital resources limits potential application scenarios. Consequently, enhancing the performance and reach of Yunnan's low-altitude economy, as well as promoting the development of urban and private economies, necessitates active exploration and experimentation [2].

2 The Basic Connotation, Construction, Regional Positioning, and Spatial Spillover Effects of Low-Altitude Economy

2.1 The Fundamental Connotation of Low-Altitude Economy

As an emerging concept, the low-altitude economy has yet to establish a unified industry consensus and a clear definition. Nevertheless, the academic community characterizes it through several key attributes. The low-altitude economy is intricately linked to both production and daily life, representing a contemporary geographical phenomenon in low-altitude regions. It has evolved from a mere conceptualization of atmospheric space to a geographical entity comprising natural, social, and economic subsystems. This encompasses temporal and spatial elements, topography, surface conditions, climate, constraints posed by extreme disasters, as well as knowledge, technology, resource commonality, social equity, and economic value. Consequently, the low-altitude economy represents a natural regional complex that integrates these diverse natural, social, and economic attributes. From a natural perspective, low-altitude airspace primarily refers to the near-Earth space with a vertical height below 1,000 meters, although it may extend up to 3,000 meters based on practical needs. Due to the influences of atmospheric movements and terrain, low-altitude airspace exhibits distinct regional variations. From a social perspective, low-altitude airspace serves as a crucial spatial venue for human production and daily life, accommodating various societal activities such as transportation, communication, reconnaissance, defense, and early warning. Economically, low-altitude airspace is a strategic resource, and its effective development can yield significant commercial value. It represents an ideal domain for expanding human production and living spaces and embodies a novel three-dimensional economic form, characterized by the integration of elements across three dimensions and cross-boundary industrial collaboration [3-4].

2.2 Construction of the Low-Altitude Economy Industrial Chain

The industrial ecosystem is a network of relationships formed by the interactions of elements that significantly influence the development of a particular industry [5]. It encompasses not only enterprises and institutions closely related to product development, production, delivery, and usage at various stages of the industrial chain, but also

includes application scenarios, users, government, infrastructure, laws, regulations, and policies that support industrial development. Collectively, these elements constitute the support system for the operation and development of the industry, forming an essential part of the industrial ecosystem. The low-altitude economy represents both an aggregation of multiple industries and a complex industrial ecological circle [6].

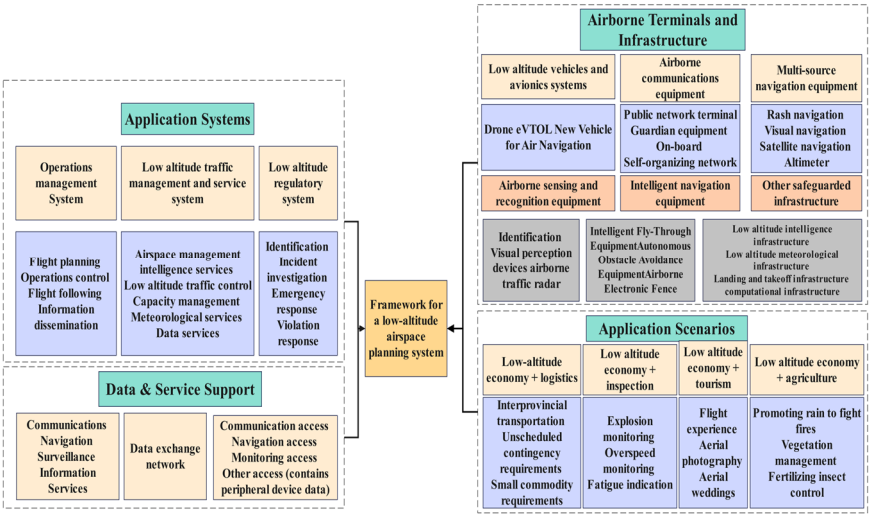

Fig. 1. Framework Diagram of Low Altitude Airspace Planning System

The low-altitude economy primarily encompasses four major sectors: low-altitude airspace, low-altitude aircraft, low-altitude applications, and low-altitude infrastructure. Low-altitude airspace serves as the foundation of the low-altitude economy, encompassing the near-ground space below 1,000 meters. Low-altitude aircraft include general aviation aircraft, drones, electric vertical takeoff and landing vehicles (eVTOLs), and their associated ground equipment, as well as upstream products such as energy sources, power systems, components, materials, and software. Low-altitude applications represent the core of the low-altitude economy, comprising operational applications such as agricultural monitoring, plant protection in agriculture and forestry, geographic mapping, industrial inspections, mineral exploration, and communication relays; transportation applications such as mountain logistics, instant delivery, air taxis, emergency medical services, intercity aviation, and private flights; consumer applications including tourism sightseeing, aerial performances, flight competitions, and flight experiences; and safety applications such as firefighting, police security, emergency rescue, and traffic law enforcement. Low-altitude infrastructure encompasses both physical and information systems. Physical infrastructure includes general aviation airports, takeoff and landing bases, charging stations, and maintenance stations. Information infrastructure consists of communication networks, sensing networks, navigation networks, computing power networks, meteorological networks, storage platforms,

analysis platforms, sharing platforms, and security platforms. The low-altitude flight support industry covers various aspects such as airspace management, airspace application services, spatial security defense, inspection and testing, flight training, facility maintenance, and financial insurance, as shown in Figure 1[7].

Low-altitude economic activities are constrained by various laws, regulations, policies, and standards. The regulatory bodies involved encompass both central and local government departments, including those responsible for military aviation, civil aviation, transportation, industry and information technology, public security, and market regulation. Participants in this sector extend beyond enterprises within the industrial, supply, value, and innovation chains; they also include universities, research institutions, users, intermediary service organizations, and government agencies.

2.3 Regional Positioning Advantages of Yunnan's Low-Altitude Economy

As a groundbreaking approach to integrating new production factors, the low-altitude economy is reshaping the spatial logic of urban development. For Yunnan, a frontier province characterized by uniquely three-dimensional geographical features, this transformation represents a strategic opportunity to transcend the limitations of traditional transportation networks. Yunnan serves as a crucial gateway and forefront for China's engagement with Southeast Asia, South Asia, and the surrounding Indian Ocean region. Its civil aviation routes have achieved comprehensive coverage of the capitals and key tourist cities in both South Asia and Southeast Asia. With a border extending approximately 4,060 kilometers and sharing boundaries with Myanmar, Laos, and Vietnam, Yunnan's mountainous terrain, which constitutes 98.4% of its land area, not only presents natural barriers to land transportation construction but also creates unique application scenarios for the low-altitude economy. Research indicates that incorporating low-altitude elements can significantly reduce the transportation time of materials in mountainous areas compared to traditional methods. The extensive economic radiation radius of this approach provides a robust spatial foundation for the reorganization of production factors in the Yunnan Plateau region [8]. Policy empowerment at the national level has accelerated the practical progress of the low-altitude economy in Yunnan. The introduction of the "Three-Year Action Plan for the Development of the Drone Industry in Yunnan Province" signifies the elevation of the low-altitude economy from mere industrial planning to a comprehensive regional development strategy. By establishing a "seven-in-one" industrial system, Yunnan is concentrating on fostering industrial clusters such as general aviation manufacturing, low-altitude logistics hubs, and intelligent air traffic control systems. This strategic framework not only aligns with the cross-border connectivity requirements of the national "Belt and Road" initiative but also holds significant value for the modernization of border governance [9]. The development of low-altitude transportation networks can enhance the accessibility of public services in border regions, and its spatial spillover effects contribute to the emergence of a new developmental paradigm along the border. Currently, the synergistic effects of the low-altitude economy and urban development have already been observed in certain regions. The Shenzhen General Aviation Association has proposed a "Scenario-Driven, Ecosystem Co-Construction" strategy, which aims to cultivate practical talents

through the "Entrepreneurial Industry-Education Integration" model to address the industry's talent shortage. The Department of Agriculture and Rural Affairs of Zhejiang Province is actively expanding the application of the "low-altitude economy + agriculture" model, with the objective of achieving comprehensive coverage of agricultural drones in provincial-level modern agricultural service centers by the year 2027. The province aims to maintain a fleet of over 10,000 agricultural drones, which will operate across an area exceeding 65 million mu, and to establish 100 intelligent monitoring points, thereby ensuring that rural drone patrols cover more than 30% of the area. Concurrently, the Central Yunnan New Area is planning the construction of the Future Transportation (Yunnan) Science City, with the goal of creating a headquarters cluster for the low-altitude economy. On May 26, 2024, the Yunnan Low-altitude Economy Industrial Park was inaugurated in Mile City, promoting the integrated development of the "low-altitude economy + tourism" model and transforming the tourist experience [10]. These advancements indicate that the incorporation of low-altitude elements is redefining the functional positioning of border cities, with their spatial economic value significantly surpassing that of traditional industries, thus providing innovative impetus for the coordinated development of regional economies.

Based on this, this study constructs an innovative analytical perspective for the development of plateau cities in Yunnan at the theoretical level. Traditional regional economic theories exhibit limitations in elucidating economic activities within three-dimensional spaces, whereas the 'vertical space development' model of the low-altitude economy transcends the resource constraints imposed by two-dimensional planes. By analyzing the interaction mechanism between low-altitude elements and urban spatial reconstruction, this study reveals the catalytic effect of new low-altitude equipment sharing on regional economic integration. At the practical level, Yunnan's research value as an innovation testbed for the low-altitude economy becomes increasingly prominent: its three-dimensional topography serves as a natural laboratory for verifying the economic feasibility of low-altitude technology applications, while its plateau urban location provides a policy testing space for exploring cross-border low-altitude economic cooperation. This holds exemplary significance for nurturing new quality productive forces in similar regions across the country and introduces a novel lifestyle model that aligns with people's aspirations for a better life.

2.4 Spatial Spillover Effects of the Low-Altitude Economy

The low-altitude economy systematically develops airspace resources below 3,000 meters, forming a comprehensive value chain that encompasses equipment manufacturing, operational services, and digital governance. This economic model exhibits dual spatial attributes: at the physical space level, it transcends the limitations of two-dimensional planes, enabling the vertical allocation of production factors; at the virtual space level, it leverages digital twin technology to construct airspace management platforms, thereby creating a scheduling system that integrates the virtual and the real. The unique three-dimensional terrain of Yunnan accentuates the spatial penetration effect of the low-altitude economy. The drone logistics network can overcome the barriers posed by the Hengduan Mountains, connecting border villages to the regional economic cycle

and significantly expanding its economic radiation radius compared to traditional transportation methods.

The spatial spillover effect influences the regional development system through three dimensions [11]. In the dimension of factor mobility, the networked layout of low-altitude infrastructure dismantles administrative barriers, facilitating the cross-regional reorganization of factors such as labor and capital along aerial corridors. The Dianxi Biomedical Industry Belt extends the radius of medicinal material collection to remote mountainous areas through drone cold-chain transportation, reaching regions that are challenging to access via traditional land transport, and driving the coordinated development of upstream and downstream enterprises across county industrial clusters. In the dimension of industrial linkage, the low-altitude economy catalyzes the upgrading of traditional industries through technology spillover. Tourist sightseeing helicopters and ground-based homestays create a three-dimensional consumption scenario, prompting the "low-altitude + industrial chain" to extend into cultural experiences and ecological protection. The multiplier effect of this industrial integration has demonstrated a 1:5 surrounding industry driving coefficient in the low-altitude tourism demonstration zone of Diqing Tibetan Autonomous Prefecture. Furthermore, the low-altitude economy contributes to the development of the health tourism pilot zone in western Yunnan, the cultural health tourism belt, and the hot spring health tourism belt, thereby promoting the development of health tourism routes and cultural creative products, further expanding the regional economic development space.

The two-way driving mechanism of institutional innovation and technological advancement has significantly enhanced the restructuring capability of the low-altitude economy [12]. The airspace classification management pilot implemented in Yunnan has dynamically matched public service needs, such as border patrol and emergency rescue, with commercial flight airspace, achieving composite utilization of limited airspace resources. Private enterprises, particularly in the aviation sector, have emerged as the primary drivers of technological innovation in this process. By integrating meteorological data with real-time flight data, these enterprises have substantially improved the efficiency of logistics distribution in mountainous areas. The positive externalities resulting from the diffusion of low-altitude technology have catalyzed the transition of the low-altitude economy from isolated breakthroughs to a networked development model, with its spatial spillover effects continuing to expand alongside the enhancement of the digital twin airspace management platform.

The unique time-space compression effect of the low-altitude economy [13] has restructured the spatial economic relationships within the Yunnan Plateau region. The traditional 'distance decay law' in geography has experienced significant alterations due to the influence of low-altitude elements, thereby redefining the spatiotemporal distance between border ports and inland hinterlands. The drone logistics hubs established along the China-Laos Railway, utilizing the 'rail-air intermodal transport' model, leverage the scale advantages of land transport alongside the speed benefits of air transport, thereby forming a cross-border supply chain network aimed at South and Southeast Asia. This transformation not only reconstructs the regional economic geography but also promotes new models of regional cooperation, thereby opening a three-dimensional channel for Yunnan's integration into the new development paradigm.

2.5 Urban Development Evaluation System from the Perspective of Low-Altitude Economy

The urban development evaluation system, viewed through the lens of new quality productivity, transcends the limitations of traditional economic indicators by establishing a multidimensional observation framework. This framework incorporates the efficiency of factor allocation [14], the dynamics of technological innovation [15], and the capacity for institutional coordination [16]. In light of the three-dimensional spatial development characteristics of the low-altitude economy, this system emphasizes the assessment of a city's ability to transition from planar expansion to a three-dimensional leap in both quality and efficiency.

In terms of the efficiency of factor allocation, the evaluation indicators primarily focus on the recombination efficiency of new production factors, such as capital, technology, and data, in low-altitude scenarios. Notably, it emphasizes the capacity of private enterprises to integrate resources across domains through innovative business models. The spatiotemporal compression effect on the circulation of characteristic agricultural products in the mountainous areas of Yunnan, facilitated by the low-altitude logistics network, alongside the degree of vertical integration of the regional industrial chain driven by general aviation equipment manufacturing, serves as crucial observation points for assessing the optimization of factor allocation. Regarding the momentum of technological innovation, the evaluation module prioritizes the analysis of the R&D investment conversion mechanism led by private enterprises. By monitoring the speed of technology diffusion and the efficiency of patent conversion in low-altitude application scenarios, it elucidates the quality of nurturing a new industrial ecosystem. The unique three-dimensional terrain of Yunnan serves as a natural testing ground for technological innovations, including drone airworthiness testing and the development of intelligent air traffic control systems. Consequently, the evaluation system has integrated a technical adaptability index to measure the precision of innovative solutions in addressing the actual needs of border regions, effectively capturing the multiplier effect of technological breakthroughs by private tech enterprises in areas such as vertical takeoff and landing, as well as high-altitude weather adaptation, on the enhancement of urban capabilities. Regarding institutional synergy capability, the system quantifies assessments to transcend the traditional paradigm of policy effectiveness evaluation, constructing a dynamic feedback mechanism observation model to monitor the synergy between airspace management reforms and market access innovations, alongside the amplification effect of government-guided funds on leveraging private capital. In the context of development and opening-up along the border in Yunnan, the innovative institutional design of cross-border low-altitude corridors and the docking efficiency of digital border trade platforms are incorporated into core indicator monitoring, reflecting the support intensity of new production relations for the export-oriented economy of border cities.

Moreover, the evaluation system innovatively introduces a spatial efficiency index that quantitatively characterizes the quality of urban spatial restructuring. This is achieved by calculating the coverage rate of low-altitude infrastructure networks over traditional transportation blind spots and the increase in economic density generated by

three-dimensional space development. Additionally, it employs low-altitude monitoring networks to conduct three-dimensional monitoring of ecologically sensitive areas within biodiversity protection zones. The system also considers the cost-saving effects of environmental governance through drone patrols, collectively forming distinctive indicators for spatial efficiency evaluation. The contributions to the functional optimization of cities on the Yunnan Plateau provide a decision-making basis for selecting unique urban development paths [17].

The evaluation system, viewed from the perspective of new quality productivity, places significant emphasis on the sustainability of development models. It incorporates observation dimensions such as the contribution rate of green technology innovation and the conversion rate of ecological value. In low-altitude tourism demonstration zones, the system assesses the environmental carrying capacity of three-dimensional space development by quantitatively analyzing the correlation between the substitution rate of new energy in aviation vehicles and the reduction in carbon footprint. This design enables the evaluation system to effectively guide urban development from scale expansion to quality enhancement, providing a scientific assessment tool for the sustainable development of ecologically sensitive regions, such as Yunnan.

3 Analysis of the Multidimensional Characteristics of Urban Development in Yunnan

3.1 Spatial Distribution Pattern of Low-Altitude Economy Infrastructure Construction

The spatial distribution of low-altitude economic infrastructure in Yunnan has established a dynamic correlation with geographical conditions, industrial support, and policy guidance, exhibiting a multi-centered network pattern [18]. As the core of the Central Yunnan Urban Agglomeration, Kunming has leveraged the aviation hub status of Changshui International Airport to advance the construction of intelligent drone takeoff and landing stations and airspace management data centers, thereby establishing a low-altitude traffic command center that serves the entire province. By continuing the agglomeration characteristics of traditional air transportation and achieving deep integration of physical facilities with virtual space through digital twin technology, Kunming has significantly enhanced the systemic resilience of the low-altitude network. In the Hengduan Mountain region of western Yunnan, the infrastructure layout has adopted a distributed node model, prioritizing the establishment of vertical take-off and landing platforms in areas with challenging transportation, such as Nujiang and Diqing. This strategy transcends the linear limitations of traditional transportation networks, opting instead for a three-dimensional spatial layout based on practical needs, including emergency rescue and agricultural and forestry operations.

The gradient distribution characteristics of infrastructure are influenced by both policy guidance and market forces. In the Central Yunnan New Area and the border economic cooperation zones, the aviation industrial park and low-altitude service support platform are prioritized, forming a pilot demonstration zone for institutional innovation

[19]. Private enterprises, responding to market demand, extend along the industrial chain and independently invest in constructing landing sites for distinctive agricultural production areas such as coffee and Chinese medicinal herbs, resulting in a pearl-chain-like distribution. This mechanism, which harmonizes government planning with market choices, leads to a significantly higher density of infrastructure in the Zhaotong apple industrial belt compared to other similar regions, highlighting the role of efficient allocation of production factors in shaping spatial patterns. The three-dimensional layout of infrastructure fosters new spatial economic relationships [20].

3.2 The Path of Urban Industrial Transformation Driven by New Quality Productivity

The urban industrial development in Yunnan is currently undergoing a profound reconstruction of its foundational logic, driven by the comprehensive integration of new quality productive forces. This transformation is characterized by multidimensional breakthroughs and three-dimensional integration. Under the influence of low-altitude economic elements, the spatial organizational paradigm of traditional industries has fundamentally shifted, gradually establishing a new industrial ecosystem centered on vertical integration. This shift is first evident in the reorganization and optimization of production factors within three-dimensional space, where the establishment of a drone logistics network effectively overcomes geographical barriers in mountainous regions, systematically integrating previously dispersed agricultural resources into a modern supply chain system [21]. Private logistics enterprises, such as the Pu'er Tea Park, have innovatively developed an integrated "drone + cold chain" transportation solution. This innovation has achieved seamless connectivity between high-altitude tea plantations and advanced processing bases, enhanced the added value of tea products, and subsequently fostered a new business model that integrates production, processing, and experiential tourism.

The vertical extension of industrial chains, triggered by the diffusion of technological innovation, has emerged as a core driving force behind the advancement of urban industrial capabilities. The construction of industrial ecosystems underscores the importance of reconstructing spatial economic relationships [22]. The networked configuration of low-altitude economic infrastructure facilitates the transformation of urban functions from planar agglomeration to three-dimensional distributed development. In the Central Yunnan Urban Agglomeration, aviation industrial parks and digital economy zones are interconnected by aerial corridors, enabling collaborative efforts in research and development, airworthiness testing, and data services across parks. Private enterprises, via shared airspace management platforms, effectively integrate low-altitude logistics distribution networks with ground industries such as specialty agriculture and e-commerce. This integration forms a composite industrial ecosystem characterized by a 'sky network + ground network' model, which propels the cluster development of supporting service sectors, including packaging design and brand marketing.

Institutional innovation provides sustained momentum for industrial transformation. The "Negative List" management system for the low-altitude economy implemented in Yunnan has invigorated private enterprises' investment vitality by relaxing market

access. In cross-border tourism cooperation zones, the joint low-altitude sightseeing operation model developed through government-enterprise collaboration innovatively bundles airspace usage rights with tourism resource franchise rights, extending tourism services from scenic sightseeing to low-altitude experiences. This successful alignment of institutional supply with market demand fosters a virtuous cycle of "application scenario innovation - business model iteration - technology standard output," providing institutional guarantees for cultivating unique and competitive industries in plateau cities. Currently, industrial transformation is deepening towards sustainability and intelligence. The integrated application of new energy aircraft development and carbon footprint monitoring technology indicates that urban industrial development is entering a new stage of transformation of ecological value [23].

3.3 Special Challenges in Urban Development in Yunnan Region

As a crucial hub in the "Belt and Road" strategy and a province abundant in tourism resources, Yunnan must focus on several key areas during its economic structural transformation and upgrading. First, it should thoroughly develop and optimize its unique resource advantages to effectively address the intrinsic needs of urban development and enhance the endogenous driving force of economic growth. Second, by constructing new industrial cities, strategically planning the layout of industries, and judiciously selecting industry types, Yunnan should promote the optimization and restructuring of urban spatial structures, thereby providing favorable conditions and solid guarantees for the sustainable development of private enterprises. Currently, the spatial restructuring challenges faced by Yunnan's urban development arise from its complex geographical environment, social structure, and institutional conditions. The unique three-dimensional topography and multi-ethnic settlement characteristics create dual spatial tensions in the process of integrating low-altitude economic elements, resulting in localized and imbalanced spatial economic growth. On one hand, the three-dimensional geographical barriers formed by karst landforms and the Hengduan Mountains lead to high construction costs for low-altitude infrastructure networks. This situation necessitates a careful balance between ecological conservation redlines and the settlements of ethnic villages in the planning of drone takeoff and landing points. On the other hand, the cultural diversity within the cross-border ethnic economic circle presents challenges in reconciling the protection of traditional livelihoods with the introduction of modern industries in the commercial utilization of airspace resources. This spatial contradiction is particularly pronounced in border port areas, where the planning of cross-border low-altitude logistics corridors must simultaneously address national defense security needs and traditional border trade practices. The complexity of the institutional design in this context far exceeds that of general regional development issues.

3.3.1 The Coordination Dilemma of Multidimensional Institutional Innovation, Deeply Constraining Urban Development in Yunnan.

Airspace has historically posed significant challenges for civil aviation. The restrictions on airspace not only hinder the development of public transport aviation in

China but also obstruct the burgeoning aspirations of general aviation. The reform of low-altitude airspace management is not merely an expectation within the civil aviation sector; it is also a crucial strategic initiative endorsed by the Party and the state. However, this reform involves multiple stakeholders, including civil aviation authorities, the military, and border defense agencies. Additionally, it necessitates the alignment of international aviation regulations with local ethnic autonomous provisions in cross-border ethnic regions, which calls for tailored airspace management reforms in these areas. For example, the airspace approval for the low-altitude sightseeing project in Xishuangbanna must adhere to the technical specifications outlined in the "Civil Unmanned Aircraft System Air Traffic Management Measures" while also respecting the sacred mountain belief space protection agreements established by the Dai villages. The demand for cross-level and cross-domain institutional coordination has significantly increased policy implementation costs. Concurrently, private capital faces unique cultural adaptation challenges when engaging in the low-altitude economy. To effectively promote services, there is a need to innovatively integrate modern logistics systems with the traditional material circulation of ethnic festivals, thereby achieving a localized transformation of the business model.

3.3.2 The Adaptation Issues of New Production Factors in the Socio-Cultural Dimension.

The three-dimensional spatial development model, driven by the low-altitude economy, has created friction with the long-established, flattened governance structure in multi-ethnic regions. In areas with traditions of nature worship, such as the Dongba culture of the Naxi people, drone services are offered for low-altitude sightseeing. However, it is essential to avoid sacred areas and to strictly control flight altitudes to prevent damage to these sacred natural landscapes and to avoid cultural conflicts.

3.3.3 The Intensification of Spatial Differentiation Risks in Yunnan's Urban Development Exacerbates the Heterogeneous Flow of Production Factors.

Although the vertical penetration capability of low-altitude economic elements can facilitate the infusion of capital and technology into mountainous regions, a significant disparity exists in the efficiency of element absorption due to the structural deficiencies in human capital within ethnic areas. The adoption of new technologies in minority regions, such as Miao and Yi villages, is markedly delayed, with challenges such as language barriers and the lack of skill training systems becoming increasingly prominent. This spatial imbalance in the efficiency of element allocation may exacerbate the developmental gradient within border cities, highlighting the need for more targeted human capital enhancement strategies for ethnic regions to effectively address these issues.

4 Research on the Collaborative Development Mechanism of the Private Economy

4.1 Low-Altitude Economy Industrial Chain and the Embedding Model of Private Enterprises

The construction of Yunnan's low-altitude economy industrial chain exhibits distinct characteristics of vertical integration, forming a multidimensional system that is driven by innovative application scenarios, supported by technological research and development, and extended through ancillary services. This industrial chain comprises a dual structure: the core layer and the application layer. The core layer concentrates on foundational areas, including general aviation manufacturing and the development of airspace management platforms. Here, private enterprises have successfully overcome the bottlenecks associated with plateau-compatible equipment through significant technological breakthroughs. The application layer diversifies business formats via the 'low-altitude +' model, with private capital innovating service delivery in contexts such as tourism, emergency rescue, and smart agriculture. This approach activates the commercial potential of Yunnan's three-dimensional geographical space and enables private enterprises to identify differentiated embedding strategies across various segments of the industrial chain [24].

The key for private enterprises to integrate into the industrial chain lies in achieving bidirectional breakthroughs in technological innovation and business models. In the realm of equipment manufacturing, the development of an intelligent obstacle avoidance system and a power optimization module, both possessing independent intellectual property rights, can effectively address the complex meteorological conditions prevalent in plateau mountainous areas, with their technical indicators reaching a leading level within the industry. These innovative achievements are rapidly translated into practice through a collaborative mechanism involving industry, academia, and research. At the service application level, private enterprises have creatively devised a 'shared airspace' operational model, which intelligently aligns public service demands—such as agricultural and forestry plant protection and power inspection—with commercial flight missions via a dynamic route planning system, significantly enhancing the utilization efficiency of low-altitude resources.

4.1.1 Ecological Co-Construction Model.

The government facilitates private capital's involvement in the development of low-altitude economic zones through industrial funds, allowing enterprises to share in the profits of infrastructure operations by contributing technology as equity. President Xi Jinping emphasized that "the people's aspiration for a better life is the goal of our Party," highlighting the necessity of providing high-quality ecological products to satisfy the populace's increasing demand for a beautiful ecological environment [25]. The "Guiding Opinions" designate "serving the people" as a primary objective, asserting that "the country adheres to the principle of sharing benefits with all, focusing on enhancing ecosystem service functions, promoting natural environment education, and offering

the public opportunities to engage with nature and rest as part of national welfare." By establishing collaborative platforms, the government has created a cohesive system where platform developers, stakeholders, and users can work together. This gradual establishment of a low-altitude interactive ecosystem aims to facilitate two-way communication, immersive experiences, and collaborative sharing.

4.1.2 Technology Spillover Model.

Leading enterprises will open their technical standards to support small and medium-sized enterprises, thus driving a comprehensive upgrade of the regional industrial chain following the completion of aircraft airworthiness certification. By digesting and absorbing technology, these enterprises expand their internal knowledge base, adopt incremental innovations, and globally reference or imitate mature technical standards or products. In the early stages of development, they are constrained by their own technological capabilities and the limitations of local industrial development levels. This situation allows for technological progress, enabling them to gradually catch up with leading enterprises. Alternatively, by integrating their own technical strategies, they can horizontally extend their technology, resulting in the derivation of a series of technological sub-tracks based on learning and imitation.

4.1.3 Scenario Co-Creation Mode.

Driven by scenario-based demands, the acceleration of the multiplier effect of the low-altitude economy is essential. From an operational logic perspective, the core mechanism for transforming data elements into new quality productivity involves leveraging institutional intermediaries for data elements. These intermediaries, guided by specific scenario-based demands, expedite the process of data valorization, facilitate effective cross-scenario circulation of data value, and activate the ecosystem of data elements. Consequently, this promotes the transformation of data resources into new quality productivity across multiple scenarios. In the context of the low-altitude economy, realizing data value heavily depends on the unique data characteristics of specific scenarios. Different scenario features correspond to various ecosystem actors and pathways for value realization. Therefore, it is imperative to focus on the scene-driven innovation paradigm. Government departments should gain in-depth insights into the specific needs of regions, industries, organizations, and users across different scenarios. By leveraging institutional mechanisms such as service procurement agreements, they can effectively guide the rapid flow of high-value data elements toward distinctive scenarios, such as low-altitude emergency rescue and cross-border logistics. This approach will help establish a data application ecosystem driven by the institutional mediation of the low-altitude economy, forming a stable and sustainable business model. This approach will not only leverage rich scenario-based applications to continuously stimulate new momentum in the low-altitude economy and effectively enhance market vitality, but it will also promote the comprehensive transformation of the low-altitude economy sector from being driven by data elements to new quality productivity, thereby fully unleashing the multiplier effect of low-altitude economic development. Three typical models will be established to integrate private enterprises into the industrial chain. The

first model is the ecological co-construction model, where the government guides private capital to participate in the construction of low-altitude economy parks, allowing them to share in the operational benefits of infrastructure through industrial funds, with enterprises contributing technology as equity. The second model is the technology spillover model, wherein leading enterprises open their technical standards to support small and medium-sized enterprises, thereby driving a comprehensive upgrade of the regional industrial chain following the airworthiness certification of aircraft. Finally, the scene co-creation model facilitates collaboration between private enterprises and local governments through service procurement agreements to develop distinctive applications such as low-altitude emergency rescue and cross-border logistics, ultimately forming a sustainable business model. The practices observed in the Central Yunnan Urban Agglomeration demonstrate that the flexibility and innovative vitality of private enterprises can effectively address the supply gap in public services.

4.2 Analysis of the Development of Yunnan's Characteristic Private Economy Clusters

The synergistic effect of three-dimensional spatial development and institutional innovation is evident in the cultivation practices of Yunnan's unique private economic clusters. Through innovations in technological adaptability and scenario-based applications, facilitated by the low-altitude economy, private enterprises have established a distinctive model of industrial agglomeration. The composite industrial cluster, characterized by 'drone monitoring + ecotourism,' has transcended the spatial limitations of traditional industries. The infrared remote sensing drone system developed by technology companies enables three-dimensional monitoring of rare species, with its data services leading to the creation of ecological value assessment products. Meanwhile, tourism companies have innovated the Dianchi low-altitude seagull-watching route, effectively transforming scientific research data into immersive experiential projects. This division of labor within the cluster has cultivated positive interactions between technological research and development and commercial operations, thereby promoting the organic integration of ecological protection with economic development objectives.

4.2.1 The Decisive Impact on the Quality Development of the Private Economy.

Yunnan has implemented a policy package characterized by 'scenario opening and standard co-construction' to stimulate the innovative vitality of private enterprises through low-altitude application scenarios. In the realm of cross-border logistics, the government has empowered logistics enterprises to partake in the formulation of the 'Operation Standards for Cross-Border Drone Corridors,' thereby establishing a collaborative mechanism whereby enterprises explore pathways while the government sets standards, with Mohan Port designated as the pilot site. This institutional design facilitates the deep involvement of private capital in localizing and adapting to international aviation regulations, while simultaneously exploring business models, fostering professional clusters, and enhancing cross-border service capabilities.

4.2.2 The Path of Technology Diffusion Exhibits Spatial Gradient Characteristics During the Development of the Private Economy.

As a technological hub, the Kunming UAV manufacturing base extends its technological capabilities to frontier regions through a collaborative innovation network within the industrial chain. In response to the unique characteristics of slope lands for small-grain coffee cultivation, agricultural enterprises in Dehong Prefecture have developed a variable spray control system that encourages core enterprises to optimize product design, thereby creating a bidirectional interactive mechanism of 'central and peripheral innovation.' Furthermore, the talent mobility mechanism established within the cluster, coupled with a shared testing platform, enhances the recombination efficiency of technological elements in three-dimensional space, thereby promoting the continuous enhancement of the resilience of the industrial chain.

4.2.3 The Development Level of Clusters is Directly Influenced By the Quality of Market Ecosystem Cultivation.

Yunnan has established a differentiated competitive landscape in the low-altitude tourism sector by creating an 'application scenario pool' that guides private enterprises in precisely addressing market demands. Dali's private aviation enterprises have developed water-based drone sightseeing projects with a focus on the ecological protection of Erhai Lake. Meanwhile, enterprises in Lijiang have innovated helicopter glacier exploration products, leveraging the terrain of the Jade Dragon Snow Mountain. This strategy of differentiated development, which avoids homogenized competition, fosters complementary and symbiotic industrial ecosystems within the cluster. More importantly, by forming a low-altitude service alliance, private enterprises share airspace resources and flight data, significantly reducing operational costs while enhancing service responsiveness. This collaborative approach injects momentum into the sustainable development of characteristic industrial clusters in border regions.

5 Conclusion

5.1 Multi-Subject Collaborative Governance Should Emphasize Policy Innovation from the Perspective of Modernizing Frontier Governance

The core of this study lies in optimizing the allocation of elements, innovating spatial governance, and fostering market entities to establish a synergistic mechanism. The low-altitude economy empowers the sustainable development of frontier regions, necessitating the urgent construction of a systematic policy support framework. Policy design should consider Yunnan's three-dimensional geographical and cultural characteristics, emphasizing the dynamic balance between spatial development and ecological protection. It is essential to establish a classified management system for airspace resources, incorporating ecological redline zones and ethnic cultural protection areas into the negative list of the low-altitude economy. Furthermore, intelligent adaptation of flight activities to the natural environment should be achieved through dynamic route planning technology. In the realm of infrastructure construction, promoting cross-

administrative regional cooperation based on digital twin technology is vital. This includes building a cloud platform for low-altitude resource management and ensuring the full connectivity of takeoff and landing sites, as well as the interoperability of meteorological data and airspace information. These measures will effectively address issues such as the low utilization rates of facilities in Yunnan.

5.2 Innovate Market Access Mechanisms and Establish a Sustainable Development Model

Stimulating the vitality of the private economy is a key focus for sustainable development. It is essential to innovate market access mechanisms and implement a government procurement model for public services in areas such as emergency rescue and ecological monitoring. This approach guides private enterprises to enhance service quality through technological innovation. To address the demands of cross-border low-altitude economic cooperation, establishing a joint operation mechanism for a low-altitude economic corridor in South and Southeast Asia is recommended. This mechanism would allow qualified private enterprises to participate in formulating cross-border flight standards, thereby developing regional technical norms aligned with international regulations. In terms of cultivating an industrial ecosystem, emphasis should be placed on supporting the protection of intellectual property rights and brand building for distinctive business models, such as "low-altitude economy + cultural tourism" and "low-altitude economy + smart agriculture." This requires an improvement of the policy chain from "application scenario innovation" to "technical standard output" and finally to "business model promotion." The construction of a green and low-carbon development path necessitates the dual drive of institutional innovation and technological empowerment. It is recommended to guide private enterprises in accelerating the industrialization of electric vertical take-off and landing aircraft through tax incentives, green credit, and other means, while incorporating the research and development of new energy aircraft into provincial key science and technology projects. This paper proposes the establishment of a dynamic assessment system to evaluate the environmental impact of low-altitude economic activities. It suggests incorporating carbon emission indicators into the credit evaluation system of general aviation enterprises and implementing a carbon footprint tracking system in ecologically sensitive areas. Additionally, leveraging Yunnan's abundant clean energy resources, the paper explores the construction of a low-altitude transportation supply network powered by green hydrogen energy, aiming to form a sustainable development model that integrates renewable energy with three-dimensional transportation. It is recommended to create a low-altitude economic discussion platform that involves a triad of government, enterprises, and communities in decision-making processes, such as route planning and site selection for takeoff and landing points, while embedding a national cultural consultation mechanism. Furthermore, the implementation of a low-altitude skills benefit project is proposed to address the human capital shortfall in multi-ethnic regions, utilizing local vocational colleges in Yunnan to establish specialized programs in drone operation and airspace management, thereby cultivating compound talents with both technical skills and cultural sensitivity. Finally, by establishing a collaborative development fund for the border low-

altitude economy, social capital can be guided to participate in the new infrastructure construction of border counties and cities, thereby forming a sustainable development pattern characterized by government guidance, market dominance, and public participation.

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