# Research on Market Game Dynamics in Low-Altitude Logistics under Subsidy Strategies

Xue-gang Shi[1], Huan Liu[2*]

[1]School of Transportation Science and Engineering, Civil Aviation University of China, Tianjin 300300, China
[2]Institute of Airport Economics Research, Civil Aviation University of China, Tianjin 300300, China

*878889291@qq.com

**Abstract.** The logistics industry is being significantly transformed by the sustained growth of the low-altitude economy; however, how the government can effectively strengthen its regulatory role in the low-altitude logistics market remains a pressing issue. This paper investigates the interaction mechanisms among low-altitude logistics enterprises, the government, and consumers using a tripartite evolutionary game model to analyze payoff variations and equilibrium conditions under different strategy combinations. The results indicate that: an optimal interval exists for subsidy intensity, and a graduated phase-out mechanism should be adopted to achieve efficient resource allocation; penalty instruments require differentiated design to balance regulatory constraints with innovation incentives; policy resources should prioritize enterprise R&D to leverage technological innovation for demand stimulation; and the government should concentrate its efforts during the critical early window of industrial development, facilitating the market's breakthrough past the tipping point before orderly withdrawal, thereby establishing a scientifically efficient governance model.

**Keywords:** Government subsidy; R&D innovation; Low-altitude logistics; Evolutionary game theory; Consumer adoption.

## 1 Introduction

Since the inclusion of the low-altitude economy in the National Comprehensive Three-Dimensional Transportation Network Planning Outline as a key industry of the "14th Five-Year Plan" in 2021, national and local policy support has been continuously intensified, effectively stimulating market vitality. In 2024, the low-altitude economy was incorporated into the Government Work Report for the first time. Against this backdrop, last-mile delivery via logistics drones, as a pivotal application of the low-altitude economy empowering smart logistics and optimizing e-commerce "last-mile" delivery, has demonstrated significant strategic value. Low-altitude logistics delivery effectively leverages the flexibility and efficiency of UAVs, and through coordination with ground transportation, expands service coverage [1] and enhances overall delivery efficiency.


T. G. Guan et al. (eds.), *Proceedings of the 2026 4th International Conference on Digital Economy and Management Science (CDEMS 2026)*, Advances in Economics, Business and Management Research 392,
https://doi.org/10.2991/978-94-6239-699-9_43

Extensive research has been conducted on the feasibility and prospects of low-altitude logistics delivery. Rico Merkert et al. [2] highlighted its considerable development potential. Kristin Flemons MA et al. [3] argued that it offers superior flexibility, environmental sustainability, lower maintenance costs, and accessibility to remote areas. Behzad Behdani et al. [4] posited that UAVs can serve as transformative solutions, particularly in facilitating rural telemedicine applications. Regarding low-altitude economy policy and industrial integration, Hou et al. [5] proposed deepening industrial integration to cultivate distinctive economic models. Li et al. [6, 9], from a supply-side reform perspective, advocated leveraging technological innovation and air-ground resource integration. Tan et al. [7] emphasized coordinating government and market roles while consolidating infrastructure development. These studies provide important references for understanding the macroscopic framework of low-altitude economic development. In terms of specific applications, Li [8] identified scenario-driven approaches as a critical pathway for deep integration. Hong [10] classified low-altitude services into production operations, public services, and aviation consumer services, noting the growing prevalence of the latter. Liu et al. [11] explored how eVTOL aircraft can facilitate smart city renewal through tiered infrastructure planning. While these studies have enriched the understanding of application scenarios, they seldom address strategic interaction among multiple stakeholders.

In summary, the sustainable development of low-altitude logistics involves deep interaction and strategic coordination among enterprises, the government, and consumers. However, existing research exhibits notable deficiencies in tripartite evolutionary game analysis [12, 14] of the low-altitude logistics market under government subsidy strategies. Investigating whether the three parties can achieve effective collaboration is directly pertinent to the successful implementation of this sector—embodying significant potential as a new quality productive force—thereby underscoring the practical significance of studying their interaction mechanisms.

## 2 Scenario Assumptions

### 2.1 Problem Description

A subsidy and pricing game scenario is constructed involving three parties: low-altitude logistics enterprises, the government, and consumers, with the market generating social benefits. Low-altitude logistics enterprises are responsible for market operations, with their core objective being to drive technological iteration through R&D while minimizing revenue losses caused by technological obsolescence, thereby strengthening market competitiveness. The government, as the policy-making and supervisory authority, subsidizes both the R&D and production activities of low-altitude enterprises and consumers to incentivize innovation and stimulate market demand, while simultaneously regulating the market to ensure behavioral compliance. When adopting low-altitude logistics services, consumers can obtain baseline time-efficiency benefits as well as additional benefits compared to traditional delivery modes. All parties make decisions rationally with the objective of profit maximization, and market information is publicly available to all parties.

## 2.2 Model Assumptions

In the evolutionary game model (Table 1), the three game players are the government, low-altitude logistics enterprises, and consumers. All game players are in their initial states, and enterprises and consumers prioritize profit maximization as their primary objective.

**Table 1.** Model Notations and Their Definitions.

| Parameter | Description |
|---|---|
| $F$ | Base subsidy amount from the government to low-altitude logistics enterprises |
| $\varepsilon$ | Subsidy coefficient for low-altitude logistics enterprises |
| $\varepsilon F$ | Total subsidy amount allocated to low-altitude logistics enterprises |
| $G$ | Total subsidy amount for consumers upon adoption of low-altitude products |
| $Q$ | Regulatory cost of the government for the low-altitude logistics market |
| $\alpha$ | Probability of regulatory inspection for subsidized enterprises |
| $\Lambda$ | Penalty imposed on enterprises detected for subsidy fraud |
| $\varphi$ | Penalty coefficient for subsidy fraud by low-altitude logistics enterprises |
| $\varphi\Lambda$ | Total penalty amount for subsidy fraud |
| $\Omega$ | Base penalty for non-R&D enterprises under the subsidy regime |
| $\tau$ | Penalty coefficient for non-R&D enterprises under the subsidy regime |
| $\tau\Omega$ | Total penalty amount for non-R&D behavior under the subsidy regime |
| $C_1$ | R&D cost when the enterprise adopts the R&D strategy |
| $\omega_1$ | Sales revenue under the enterprise's R&D strategy |
| $\delta$ | Additional revenue from technological innovation under the R&D strategy |
| $\beta_1$ | Social benefit generated by the enterprise's R&D strategy |
| $\omega_2$ | Sales revenue under the enterprise's non-R&D strategy |
| $C_2$ | Efficiency loss due to technological obsolescence under the non-R&D strategy |
| $\beta_2$ | Social benefit under the enterprise's non-R&D strategy |
| $P$ | Additional environmental remediation cost borne by the government under the non-R&D strategy |
| $M_1$ | Consumer benefit from adopting low-altitude products |
| $M_2$ | Consumer benefit from adopting conventional products |
| $\pi$ | Additional benefit for consumers adopting the low-altitude logistics delivery mode [13] |

# 3 Model Construction

## 3.1 Payoff Matrix Construction

Within the tripartite game framework involving the government, low-altitude logistics enterprises, and consumers (Table 2), each party formulates strategic decisions based on its own interests. The probability that the government adopts a "subsidy" measure is denoted as x, with the probability of not providing subsidies being 1−x. The probability that the low-altitude logistics enterprise chooses to invest in R&D for innovative products is denoted as y, with the probability of not conducting R&D being 1−y. The probability that consumers prefer to adopt low-altitude service products is denoted as z, with the probability of non-adoption being 1−z. The strategy probabilities x, y, and z all satisfy x, y, z ∈ [0, 1].

**Table 2.** Tripartite Strategy Selection and Payoff Matrix

| Government | Enterprise | Consumer | |
|---|---|---|---|
| | | Adopt (z) | Not Adopt (1-z) |
| Subsidy (x) | R&D (y) | $\alpha\varphi\Lambda - Q - \varepsilon F - G + \beta$<br>$-\alpha\varphi\Lambda + \varepsilon F - C_1 + \omega_1 + \delta$<br>$G + M_1 + \pi$ | $\alpha\varphi\Lambda - Q - \varepsilon F + \beta_1$<br>$-\alpha\varphi\Lambda + \varepsilon F - C_1 + \omega_1$<br>$M_2$ |
| | No R&D (1-y) | $\tau\Omega + \beta_2 - P$<br>$-\tau\Omega + \omega_2 - C_2$<br>$0$ | $\tau\Omega + \beta_2 - P$<br>$-\tau\Omega + \omega_2 - C_2$<br>$M_2$ |
| Subsidy (x) | R&D (y) | $\beta_1$<br>$-C_1 + \omega_1 + \delta$<br>$M_1 + \pi$ | $\beta_1$<br>$-C_1 + \omega_1$<br>$M_2$ |
| | No R&D (1-y) | $\beta_2 - P$<br>$\omega_2 - C_2$<br>$0$ | $\beta_2 - P$<br>$\omega_2 - C_2$<br>$M_2$ |

## 3.2 Expected Payoffs of the Three Parties

Let the average expected payoffs of the government, low-altitude logistics enterprises, and consumers adopting different strategies be $\overline{E}_x$, $\overline{E}_y$, and $\overline{E}_z$. From this, the replicator dynamic equations for the three parties are obtained as follows:

$$F(X) = \frac{dx}{dt} = x(1-x)\left[\left(\alpha\varphi\Lambda - \varepsilon F - Gz - \tau\Omega - Q\right)y + \tau\Omega\right] \tag{1}$$

$$F(Y) = \frac{dy}{dt} = y(1-y)\left[\left(-\Lambda\varphi\alpha + F\varepsilon + \Omega\tau\right)x + \delta z - C_1 + C_2 + \omega_1 - \omega_2\right] \tag{2}$$

$$F(Z) = \frac{dz}{dt} = z(1-z)\left[-M_2 + y\left(xG + M_1 + \pi\right)\right] \tag{3}$$

### 3.3 Equilibrium Point Analysis

In the game system, the three participants continuously optimize their strategy selections to maximize payoffs, ultimately forming an irreversible dynamic equilibrium state. The corresponding strategies are termed evolutionarily stable strategies (ESS). The Jacobian matrix is as follows (Table 3):

$$J(x,y,z)=\begin{pmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{pmatrix} \tag{4}$$

**Table 3.** Jacobian Matrix Parameters.

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $J_1$ | $(1-2x)\left(\Omega\tau-\left(-\Lambda\alpha\varphi+F\varepsilon+Gz+\Omega\tau+Q\right)y\right)$ | $J_6$ | $(1-y)y\delta$ |
| $J_2$ | $x(1-x)\left(\Lambda\alpha\varphi-F\varepsilon-Gz-\Omega\tau-Q\right)$ | $J_7$ | $z(1-z)\,y\,G$ |
| $J_3$ | $-x(1-x)\,G\,y$ | $J_8$ | $z(1-z)\left(xG+M_1+\pi\right)$ |
| $J_4$ | $(1-y)y\left(-\Lambda\alpha\varphi+F\varepsilon+\Omega\tau\right)$ | $J_9$ | $(1-2z)\left(-M_2+y\left(xG+M_1+\pi\right)\right)$ |
| $J_5$ | $(1-2y)\left(\left(-\Lambda\alpha\varphi+F\varepsilon+\Omega\tau\right)x+\delta z-C_1+C_2+\omega_1-\omega_2\right)$ | | |

## 4 Numerical Simulation Analysis

To verify the stability results of the aforementioned tripartite game and further investigate the effects of each party's initial willingness and model parameters on system stability, $E_8(1,1,1)$ is designated as the evolutionarily stable strategy (ESS) of the system. This requires that all three eigenvalues be negative. With reference to parameter ranges established in existing government subsidy game studies and in combination with actual development data from China's low-altitude logistics industry, the initial parameter values are set as shown in Table 4.

**Table 4.** Parameter Values [14,15].

| $\alpha$ | $\varphi$ | $\Lambda$ | $\varepsilon$ | $F$ | $G$ | $\tau$ | $\Omega$ | $Q$ | $\delta$ | $\omega_1$ | $\omega_2$ | $C_1$ | $C_2$ | $M_1$ | $M_2$ | $\pi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.6 | 0.5 | 8 | 0.5 | 3 | 0.15 | 0.5 | 3 | 0.6 | 0.9 | 3 | 2.1 | 2.9 | 1.5 | 0.3 | 0.4 | 0.2 |

### 4.1 Initial Strategy Simulation Analysis

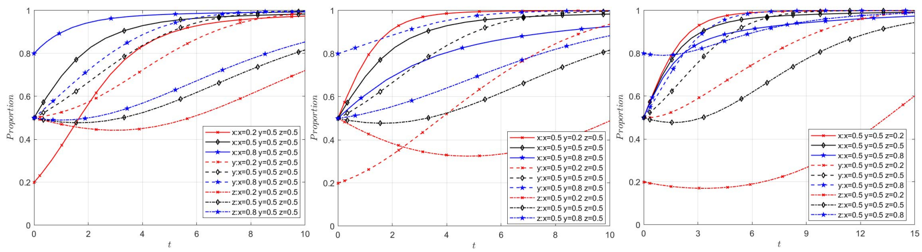


**Fig. 1.** Influence of the initial states of the government, low-altitude logistics enterprises, and consumers on the evolutionary process of each party.

To examine the sensitivity of the system to initial conditions, the three parties' initial willingness is set at 0.2, 0.5, and 0.8(Figure 1), respectively, with results shown in Figure 1. A positive feedback mechanism is observed: government subsidies promote enterprise R&D and accelerate consumer preference shifts, while higher initial willingness across all parties leads to faster system convergence toward the ideal equilibrium. Meanwhile, government subsidy policies, regulatory interventions, and consumer demand jointly serve as effective drivers of enterprises' autonomous R&D decisions.

### 4.2 Parameter Sensitivity Analysis

**Government Subsidy Coefficient.**

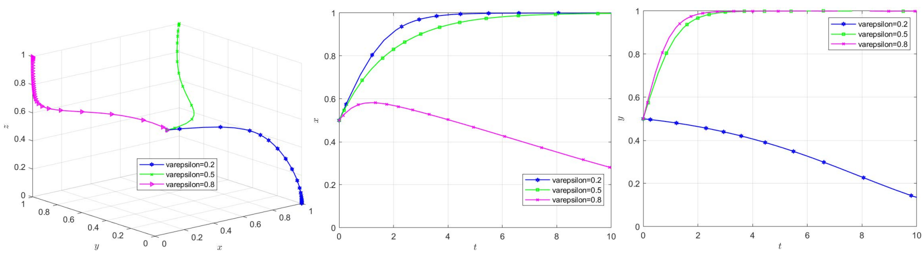


**Fig. 2.** Impact of government subsidy coefficient on enterprise strategy selection.

Under the government subsidization scenario, the subsidy coefficient is assigned values of 0.2, 0.5, and 0.8 (Figure 2). As the coefficient increases, enterprises become more proactive in R&D, since higher subsidies effectively reduce R&D costs and promote the intelligent upgrading of low-altitude logistics infrastructure, thereby encouraging consumer adoption. However, when the coefficient reaches 0.8, the government's willingness to subsidize gradually declines due to mounting fiscal pressure and relaxed regulatory oversight. This indicates that an efficiency-critical interval exists for the subsidy coefficient—beyond which enterprise and government strategies diverge. Therefore, the government should establish well-calibrated subsidy standards that balance innovation incentives with fiscal sustainability.

**Penalty Coefficient for Subsidy Fraud by Low-Altitude Logistics Enterprises.**

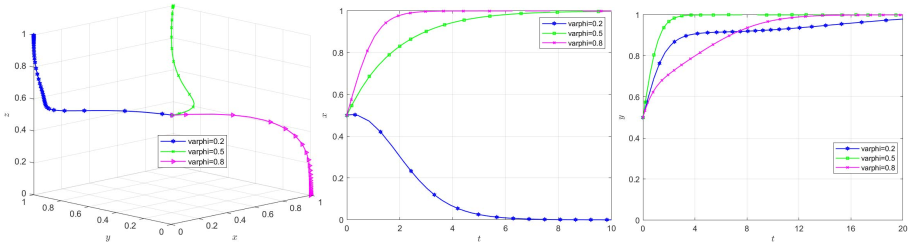


**Fig. 3.** Impact of the penalty coefficient on enterprise strategy selection.

To investigate the influence of the subsidy fraud penalty coefficient on the evolutionary game process, values of 0.2, 0.5, and 0.8 are assigned (Figure 3). At 0.2 and 0.5, enterprises converge toward the R&D strategy at an increasing rate as the penalty coefficient rises. However, at 0.8, excessively high compliance risk causes enterprises to forgo subsidy applications and associated R&D altogether, as any uncertainty during R&D may be construed as fraudulent behavior. This reveals an inverted U-shaped relationship between the subsidy fraud penalty and enterprise R&D willingness: moderate penalties incentivize compliance, while excessive penalties paradoxically suppress innovation—a "chilling effect." From the government's perspective, penalty standards are necessary to ensure subsidy accountability. From the enterprises' perspective, overly stringent penalties elevate the perceived risk of legitimate R&D, driving risk-averse withdrawal from the subsidy system. Therefore, the subsidy fraud penalty should be calibrated within an optimal interval to balance regulatory deterrence with innovation incentives.

**Penalty Coefficient for Non-R&D Production by Low-Altitude Logistics Enterprises.**

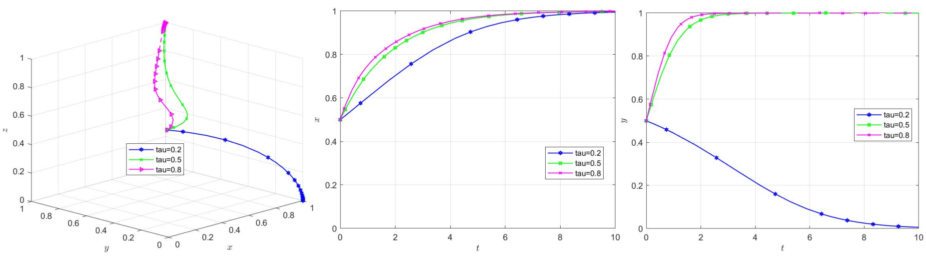


**Fig. 4.** Impact of the non-R&D penalty coefficient on enterprise strategy selection.

In practice, low-altitude logistics enterprises, similar to traditional logistics enterprises, utilize delivery facilities for goods transportation. Considering the differences in delivery equipment, values of 0.2, 0.5, and 0.8 are assigned to the penalty coefficient for non-R&D production by low-altitude logistics enterprises(Figure 4). As this coefficient gradually increases, the government's willingness to adopt the subsidy strategy also rises. This indicates that penalty payments collected from enterprises that fail to conduct R&D augment government revenues, thereby incentivizing the government to subsidize low-altitude logistics enterprises and develop supporting infrastructure for the low-altitude economy. For low-altitude logistics enterprises, as the penalty coefficient increases, enterprises prefer to proactively invest in R&D for low-altitude products to avoid paying substantial penalties. In summary, without disrupting the development of the low-altitude logistics market, the government can appropriately adjust the penalty coefficient to enhance the R&D willingness of low-altitude logistics enterprises.

# 5 Conclusions

This paper constructs a tripartite evolutionary game model involving the government, low-altitude logistics enterprises, and consumers. Using MATLAB R2024a, numerical simulations are conducted to examine the effects of initial willingness and key parameters on system evolution and stability. The main findings are as follows:

First, the subsidy coefficient exhibits an asymmetric relationship with the strategies of the three parties. An efficiency-critical interval of [0.3, 0.6] is identified, within which government and enterprise strategies are aligned and the system converges toward the ideal equilibrium. Beyond 0.7, rising fiscal pressure triggers government withdrawal, necessitating a graduated phase-out subsidy mechanism. Second, the two penalty instruments differ fundamentally in their effects. The R&D absence penalty shows a monotonically positive correlation with enterprise R&D willingness, whereas the subsidy fraud penalty must be kept within a moderate range to avoid suppressing innovation. Third, consumer adoption is subordinate to enterprise R&D outcomes. Subsidies allocated to the enterprise R&D side yield significantly greater marginal effects than direct consumer-side subsidies, indicating a supply-side priority in policy transmission. Fourth, a nonlinear take-off threshold exists in the system's initial conditions. The government should concentrate intervention during the early industrial stage to propel the market past this critical point, then withdraw in an orderly manner.

Policy Recommendations: First, implement a graduated phase-out subsidy mechanism: set higher initial subsidies with explicit reduction timelines and performance-triggered benchmarks, prioritizing R&D-side allocation through value chain joint application mechanisms and supply chain finance instruments. Second, adopt a differentiated penalty portfolio: use R&D absence penalties as the primary driver with clear output assessment criteria, while maintaining moderate subsidy fraud penalties with well-defined boundaries between technological uncertainty and deliberate fraud. Third, seize the early-stage policy window through targeted phased interventions—including demonstration projects, scenario liberalization, and technical standard formulation—supported by a dynamic evaluation system for real-time policy adjustment.

## References

1. Xiao Z P, Zhang W C, Li Y Y, et al. Air-ground coordinated organizational characteristics and challenges of low-altitude UAV delivery: A case study of Shenzhen[J]. Resources Science, 2025, 47(08): 1663-1674.
2. Merkert R, Bushell J. Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control [J]. Journal of Air Transport Management, 2020, 89: 101929-101929.
3. Kristin F, Barry B, Zeb A K, et al. The use of drones for the delivery of diagnostic test kits and medical supplies to remote First Nations communities during Covid-19 [J]. American journal of infection control, 2022, 50 (8): 849-856.
4. Behdani B. Remote Care, Flying Health: A Review of Drone Applications in Rural Telemedicine [J]. IFAC PapersOnLine, 2025, 59 (10): 1546-1551.
5. Hou G Y, Chen J T, Zhang C. Low-altitude economy empowering county-level prosperity industries[J]. Journal of Technical Economics & Management Research, 2025, (12): 1-7.
6. Li L C, Li M L. On low-altitude economy: Connotation, driving characteristics and practical pathways[J]. Journal of Beijing Jiaotong University (Social Sciences Edition), 2025, 24(04): 98-106.
7. Tan H B, Qin S J. New quality productive forces leading high-quality development of the low-altitude economy: Basic characteristics and breakthrough pathways[J]. Price: Theory & Practice, 2025, (10): 62-68.
8. Li G Y. Research on high-quality development pathways of the low-altitude economy from a scenario-driven perspective[J]. Southwest Finance, 2025, (10): 97-110.
9. Li L C, Li M L, Ma P P. Accelerating the high-quality development of the low-altitude economy[J]. Macroeconomic Management, 2025, (10): 14-20.
10. Hong Q L. Conceptual characteristics, development conditions and promotion strategies of the low-altitude service industry[J]. Economic Review, 2024, (08): 45-52.
11. Liu W J, Chen Y F, Lin W. Policy recommendations for low-altitude economy facilitating smart city renewal and development[J]. Journal of Human Settlements in West China, 2025, 40(03): 34-40. Li L C, Li M L, Ma P P. Accelerating the high-quality development of the low-altitude economy[J]. Macroeconomic Management, 2025, (10): 14-20.
12. Yu X H, He M K, Zhang Q, et al. Game analysis of blockchain-driven joint delivery for express "last-mile" delivery[J]. Operations Research and Management Science, 2020, 29(01): 17-22.
13. Lu F Q, Jiang R X, Bi H L, et al. Research on UAV-assisted rider food delivery route optimization under dynamic orders[J/OL]. Chinese Journal of Management Science, 1-11[2025-03-16].
14. Lin, Y. M., & Zhang, Z. S. (2026). Research on the impact of blockchain regulation on the green transformation of enterprise supply chains from the perspective of digital empowerment — An analysis based on the tripartite evolutionary game of government, enterprises and the public. Price: Theory & Practice. Advance online publication, 1-8.
15. Zhang, S. W., Li, Y., & Mao, X. Z. (2026). Evolutionary game analysis of policy tools and the expansion of low-altitude services of logistics enterprises. Journal of Anhui University of Technology (Natural Science). Advance online publication, 1-12.