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Research on knowledge-sharing decisions in the logistics service supply chain

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Purpose: This study investigates the knowledge-sharing decision-making mechanisms in logistics service supply chains (LSSCs), focusing on the strategic interactions between logistics service integrators and providers.
Design/methodology/approach: The study employs evolutionary game theory to model dynamic interactions in LSSCs. Numerical simulations using MATLAB are conducted to validate the theoretical findings and examine the influence of critical parameters on equilibrium outcomes.
Findings: Government incentive subsidies can effectively promote cooperation between logistics service integrators and providers. Appropriate government incentive policies help promote fair distribution of internal revenue within the logistics service supply chain and enhance the competitiveness of the overall supply chain.
Originality/value: This study pioneers a tripartite evolutionary game model for knowledge sharing in LSSCs, analyzing the relationship between government incentives and enterprise strategies relationships. By introducing parameters such as subsidy ratios, technology maturity, and trust, it extends traditional models to address collaboration dilemmas and unlock overall supply chain value.

KEYWORDS

logistics service supply chain, knowledge sharing, evolutionary game theory, digital transformation, simulation analysis

1 Introduction

With the accelerating process of global economic integration and the in-depth penetration of digital technologies, the logistics service supply chain (LSSC) has emerged as a core framework driving the upgrading of the modern logistics industry. This collaborative system, which is composed of logistics service providers, integrators, and demanders, demonstrates significant advantages in improving operational efficiency, reducing transaction costs, and enhancing market responsiveness through resource integration and process optimization. However, in practice, there are widespread knowledge barriers and information silos among various entities in the supply chain. Specifically, the regional operational experience possessed by service providers is difficult to transfer across nodes, and there is a transmission loss between the system scheduling knowledge of integrators and the personalized demands of demanders. As a result, the overall knowledge potential of the supply chain cannot be effectively converted into collaborative efficiency. Such knowledge asymmetry not only restricts the customization level of logistics solutions but also significantly increases the operational risks and coordination costs of the supply chain against the backdrop of intensified fluctuations in market demand. Therefore, exploring the driving mechanisms and decision-making logic of knowledge sharing (KS) in the logistics service supply chain has become a key proposition to solve the dilemma of inter-entity collaboration and unlock the overall value of the supply chain.

The current academic research in the field of LSSC mostly focuses on the pricing decisions, coordination mechanisms, and service quality control, among others. At the level of concept definition and theoretical construction, Cui conducted a systematic exploration of the evolution law, essential attributes, architecture model, feature analysis, and management theory system of the LSSC [1]. In terms of pricing, studies explore the structural, modal, and other factors. He et al. examined blockchain's impact via a fresh product supply chain with overseas suppliers and cross-border platforms [2]. Zhang et al. highlighted centralized decision advantages in e-commerce chains through comparative models [3]. Jiang et al. used optimal control and Stackelberg theory to determine the optimal strategies under advertising delays in fresh agricultural chains. For coordination [4], Yang and Liu (2023) applied Stackelberg game theory to a two-level cross-border logistics chain and analyzed the effects of customs clearance via factor analysis [5]. He et al. proposed a novel Stackelberg model with cost-revenue sharing to incentivize logistics capability investment [6]. Gao theoretically explained the connotation boundaries, structural paradigms, and implementation paths of the logistics service integrator (LSI) from the perspective of integration logic [7]. Qiao designed an evolutionary game model for KS within the industrialized building supply chain, grounded in the hypothesis of bounded rationality, thereby uncovering the driving mechanisms and constraints governing knowledge flow [8]. In the multi-agent sharing governance scenario, Qiu constructed a tripartite KS evolutionary game model including the government, regulators, and end-users and analyzed the moderating effect of policy intervention on KS behavior [9]. Xu considered the agricultural product supply chain as the research object and, combined with the system dynamics method, verified the positive incentive effect of government regulation on the probability of KS between growers and suppliers [10]. Regarding service quality, Zhang G and Zhang Z. linked regional logistics network stability to total revenue via an evolutionary game model [11]. Zeng et al. noted that transparent information environments encourage CCL providers to enhance fresh-keeping, thus benefiting producers and distributors [12]. Although existing research has built multi-dimensional theoretical frameworks, it remains centered on traditional operational management. Amid the deepening digital transformation, research on digital cooperation requires further theoretical expansion.

Knowledge sharing in supply chain operations is defined as the process of building information networks to enable real-time knowledge connectivity, which facilitates collaborative practices among firms. As a cornerstone of modern supply chain management, its effectiveness directly enhances the decision-making quality and overall supply chain performance. High-quality knowledge flow and multi-dimensional interaction mechanisms are critical for achieving dynamic equilibrium and fostering value co-creation across supply chain ecosystems.

On the subject of supply chain knowledge sharing, Ren used stochastic Petri nets to model dynamic games, analyzing strategy evolution and expected revenue under uncertainty [13]. Qiao developed an evolutionary model for industrialized construction supply chains to identify the drivers and constraints of knowledge flow [8]. Wang and Bao explored knowledge-sharing trajectories in cluster supply chains via evolutionary games [14]. Regarding multi-agent governance, Qiu et al. built a tripartite evolutionary game model (government, regulators, and users) to analyze policy intervention effects [9]. Xu verified the government supervision's positive impact on agricultural product supply chain knowledge sharing via system dynamics [10]. Li et al. found that benefit-cost marginal differences affect the fresh produce supply chain knowledge-sharing initiative through evolutionary games [15]. Gu quantified informatization, policy incentives, and costs on logistics knowledge-sharing evolution via system dynamics [16]. Overall, existing research focuses on scenario-specific supply chain knowledge sharing, with limited studies on universal logistics service supply chains—failing to explain interest relationships and evolution paths therein, thus necessitating further exploration.

Against this backdrop, this study focuses on the LSSC, specifically examining the KS relationship between LSI and logistics service provider (LSP). By constructing an evolutionary game model, this study analyzes the strategy selection and dynamic evolution paths of both parties in the KS process. Furthermore, this study explores the decision-making mechanisms of supply chain participants in KS behavior under government policy incentives (GPIs) and identifies the key factors affecting this behavior and its underlying logic. The research results are intended to provide a theoretical reference for the practice of KS cooperation among logistics enterprises, help realize the collaborative creation of supply chain value, and promote the digital transformation process of LSSCs.

2 Tripartite evolutionary game model

Integrators, leveraging their capabilities in process optimization, data integration, and resource allocation, formulate customized matching and allocation strategies in accordance with customer demands, while maintaining advantages in user behavior analysis and technical support. In contrast, providers, relying on physical resources such as transportation equipment and infrastructure, undertake businesses including warehousing, trunk transportation, and last-mile delivery, and they possess well-developed logistics networks and professional teams. Governments, based on their own interests and social benefits, formulate incentives and subsidy policies for knowledge-sharing cooperation among enterprises to promote such collaborations. This not only contributes to enhancing their reputation in the industry but also accelerates the effective integration of logistics resources and advances the digital transformation process of the entire logistics industry. Based on this, this paper constructs a tripartite evolutionary game model comprising logistics service integrators, logistics service providers, and the government to explore the interest relationships and strategy evolution paths of all participants in the knowledge sharing process within the logistics service supply chain. It should be clarified that the knowledge mentioned in this model covers various types of sharable knowledge, which, in terms of forms of expression, includes explicit knowledge and tacit knowledge, and in terms of acquisition approaches, it includes experiential knowledge and deductive knowledge, among others.

Based on the hypothesis of bounded rationality, this chapter constructs an evolutionary game model involving logistics service integrators, providers, and the government, where the three parties make decisions as decision-making subjects aiming to maximize utility. The corresponding strategy selection probabilities are as follows: the probability of LSI engaging in KS is x, the probability of not engaging in KS is $1-x$, the probability of LSP engaging in KS is y, and the probability of not engaging in KS is $1-y$. The probability of the government providing KS incentive subsidies is z, while the probability of not providing such subsidies is $1-z$. The specific assumptions are as follows:

Assumption 1: The basic revenues of the integrator and the provider when operating independently, along with the basic revenue of the government, are denoted as R_i, respectively, with $R_i > 0$ (where i = 1, 2, and 3; 1 represents the integrator, 2 represents the provider, and 3 represents the government).

Assumption 2: Drawing on the studies by [17] and [18], this paper assumes that the total input cost for knowledge sharing between the integrator and the provider is $C_i = \frac{\alpha_i N_i^2}{2} + \frac{\beta_i^2}{2\gamma_i}$ (i = 1, 2), which consists of two components. The first component is the knowledge-sharing effort cost, $\frac{\alpha_i N_i^2}{2}$, where α_i is the effort cost coefficient for knowledge sharing, and N_i is the effort level of knowledge sharing, with $\alpha_i, N_i > 0$. The second component is the knowledge-sharing technology cost, $\frac{\beta_i^2}{2\gamma_i}$, where β_i denotes the technical level of the integrator or the data quality level of the provider, and γ_i represents the internal knowledge-sharing level of the integrator and the provider, with $\beta_i, \gamma_i > 0$.

Assumption 3: Drawing on the study by [19], it is assumed that when one party (either the integrator or the provider) chooses to share knowledge while the other does not, the knowledge-sharing party gains its own knowledge-sharing revenue $\delta_i N_i$, where δ_i is the revenue coefficient for knowledge sharing, with $\delta_i > 0$; the non-sharing party obtains a free-rider revenue $\lambda_i \delta_i N_i$, where λ_i is the incremental proportion of the free-rider revenue, with $\lambda_i > 0$.

Assumption 4: Drawing on the study by [9], this paper assumes that when the integrator and the provider reach a knowledge-sharing agreement, it generates a value co-creation revenue from supply-chain knowledge sharing, $Q\theta\sigma$, where Q is the total amount of logistics data resources, θ is the technical maturity of industry knowledge sharing, and σ is the level of trust among logistics enterprises. This value co-creation revenue is shared between the integrator and the provider, with ε being the proportion allocated to the integrator and $(1-\varepsilon)$ being allocated to the provider. It satisfies $Q, \theta, \sigma > 0$, $1 > \varepsilon > 0$, $Q\theta\sigma\varepsilon - \lambda_1\delta_2 N_2 > 0$, and $Q\theta\sigma(1-\varepsilon) - \lambda_2\delta_1 N_1 > 0$.

Assumption 5: Drawing on the research by [20], when the government provides incentive subsidies for enterprises' knowledge sharing, it gains benefits such as reputation, $\delta_3 N_3$, where δ_3 is the revenue coefficient for the government from knowledge sharing, with $\delta_3 > 0$; in this case, the government incurs an expenditure cost C_3 ($C_3 > 0$). Additionally, when all logistics enterprises engage in knowledge-sharing cooperation, the government obtains a proportion φ of the value co-creation revenue, with $1 > \varphi > 0$.

Assumption 6: The government distributes knowledge-sharing subsidies to logistics enterprises, which are allocated between the integrator and the provider at a certain ratio, where the integrator receives ω proportion, and the provider receives $1-\omega$ proportion, with $1 > \omega > 0$.

Based on the above assumptions, the payoff matrix for the evolutionary game composed of LSI, LSP, and the government is shown in Table 1:

LSI, LSP, and the government can all select the optimal strategy based on their respective benefits and other factors. In summary, the evolutionary game model is solved as follows.

The benefits for LSI when engaging in KS cooperation and when not engaging in KS cooperation are shown in Formulas 1, 2 respectively.

$$F_{a1} = yz\omega C_3 + yQ\theta\sigma\varepsilon + zC_3 - yzC_3 + R_1 + \delta_1 N_1 - C_1, \tag{1}$$

$$F_{a2} = y\lambda_1\delta_2 N_2 + R_1. \tag{2}$$

The average expected return of their KS cooperation decision is shown in Formula 3.

$$\overline{F} = xF_{a1} + (1-x)F_{a2}. \tag{3}$$

The benefits for LSP when engaging in KS cooperation and when not engaging in KS cooperation are shown in Formulas 4, 5 respectively.

$$G_{b1} = xz(1-\omega)C_3 + xQ\theta\sigma(1-\varepsilon) + zC_3 - xzC_3 + R_2 + \delta_2 N_2 - C_2, \tag{4}$$

$$G_{b2} = x\lambda_2\delta_1 N_1 + R_2. \tag{5}$$

The average expected return of their KS cooperation decision is shown in Formula 6.

$$\overline{G} = yG_{b1} + (1-y)G_{b2}. \tag{6}$$

The benefits for the government when providing KS cooperation subsidies and when not providing KS cooperation subsidies are shown in Formulas 7, 8 respectively.

$$\begin{aligned} H_{c1} = {} & xy\left[R_3 + \delta_3 N_3 + \varphi Q\theta\sigma - C_3\right] + x(1-y)\left[R_3 + \delta_3 N_3 - C_3\right] + (1-x)\,y\left[R_3 + \delta_3 N_3 - C_3\right] \\ & + (1-x)\,(1-y)\,\left[R_3 - C_3\right], \end{aligned} \tag{7}$$

$$H_{c2} = xy[R_3 + \varphi Q\theta\sigma] + x(1-y)R_3 + (1-x)yR_3 + (1-x)(1-y)R_3. \tag{8}$$

The average expected return of their KS cooperation decision is shown in Formula 9.

$$\overline{H} = zH_{c1} + (1-z)H_{c2}. \tag{9}$$

TABLE 1 Tripartite evolutionary game model.

Participants				Government	
				Incentive z	Not incentive 1-z
LSI	KS x	LSP	KS y	$R_1+\delta_1N_1+Q\theta\sigma\varepsilon+\omega C_3-C_1$ $R_2+\delta_2N_2+Q\theta\sigma(1-\varepsilon)+(1-\omega)C_3-C_2$ $R_3+\delta_3N_3+\varphi Q\theta\sigma-C_3$	$R_1+\delta_1N_1+Q\theta\sigma\varepsilon-C_1$ $R_2+\delta_2N_2+Q\theta\sigma(1-\varepsilon)-C_2$ $R_3+\varphi Q\theta\sigma$
			Not KS 1-year	$R_1+\delta_1N_1+C_3-C_1$ $R_2+\lambda_2\delta_1N_1$ $R_3+\delta_3N_3-C_3$	$R_1+\delta_1N_1-C_1$ $R_2+\lambda_2\delta_1N_1$ R_3
LSI	Not KS 1-x	LSP	KS y	$R_1+\lambda_1\delta_2N_2$ $R_2+\delta_2N_2+C_3-C_2$ $R_3+\delta_3N_3-C_3$	$R_1+\lambda_1\delta_2N_2$ $R_2+\delta_2N_2-C_2$ R_3
			Not KS 1-year	R_1 R_2 R_3-C_3	R_1 R_2 R_3

2.1 Replicated dynamic equation

1. Based on the above analysis, the replicated dynamic equation for the KS cooperation strategy of LSI is shown in Formula 10.

$$F'(x)=\frac{dx}{dt}=x(1-x)(F_{a1}-F_{a2})$$
$$=x(1-x)\left[yz\omega C_3+y(\varphi Q\theta\sigma-\lambda_1\delta_2N_2)+zC_3-yzC_3+\delta_1N_1-C_1\right]. \tag{10}$$

2. The replicated dynamic equation for the LSP KS cooperation strategy is shown in Formula 11.

$$G'(y)=\frac{dy}{dt}=y(1-y)(G_{b1}-G_{b2})=y(1-y)\left[xz(1-\omega)C_3+xQ\theta\sigma(1-\varepsilon)-x\lambda_2\delta_1N_1+zC_3-xzC_3+\delta_2N_2-C_2\right]. \tag{11}$$

3. The replicated dynamic equation for the government's KS cooperation subsidy strategy is shown in Formula 12.

$$H'(z)=\frac{dz}{dt}=z(1-z)(H_{c1}-H_{c2})=z(1-z)\left[(x-xy+y)\delta_3N_3-C_3\right]. \tag{12}$$

2.2 Model analysis and solution

Based on the dynamic replication equations of the three parties, the Jacobian (J) can be further derived as follows, as shown in Formula 13.

$$J=\begin{vmatrix} j_{11} & j_{12} & j_{13} \\ j_{21} & j_{22} & j_{23} \\ j_{31} & j_{32} & j_{33} \end{vmatrix}. \tag{13}$$

Setting $F'(x)=G'(y)=H'(z)=0$ yields eight local equilibria: $E_1(0,0,0)$, $E_2(0,0,1)$, $E_3(0,1,0)$, $E_4(0,1,1)$, $E_5(1,0,0)$, $E_6(1,0,1)$, $E_7(1,1,0)$, and $E_8(1,1,1)$. According to the evolutionary game theory, when all eigenvalues of the Jacobian matrix are negative, the local equilibrium point is an ESS. Calculating each local stable point leads to the following conclusions, which are summarized in Table 2.

The table shows that in the tripartite evolutionary game involving the LSI, LSP, and the government, the point (1, 1, 1) is identified as a stable point. Additionally, the points (0, 1, 1) and (1, 0, 1) have all negative eigenvalues, while the other points are unstable. Based on this, the following analysis is conducted.

Scenario 1: When $\omega C_3+Q\theta\sigma\varepsilon+\lambda_1\delta_2N_2+\delta_1N_1-C_1<0$, $C_2-\delta_2N_2-C_3<0$, and $C_3-\delta_3N_3<0$, the following three conditions are met: the LSI gains more benefits from not participating in KS cooperation than from participating, the LSP achieves higher returns from KS cooperation than its input costs, and the government's benefits from implementing KS incentive measures exceed its costs. Under these conditions, the system will converge toward the stable state (0, 1, 1). In this scenario, although the total net profit and subsidies received by the LSI after participating in KS cooperation are still lower than the direct costs of participation, the LSI is inclined to avoid KS (i.e., x approaches 0). However, for the LSP, the benefits gained through KS not only cover their costs but also surpass the additional income from government subsidies. As a result, they will continue to support KS cooperation. Meanwhile, the government determines that the benefits of its incentives for KS outweigh the associated costs, prompting it to sustain these incentive policies. The evolutionary trends of the entire system will ultimately converge toward (0, 1, 1).

Scenario 2: When $C_1-\delta_1N_1-C_3<0$, $(1-\varepsilon)C_3+Q\theta\sigma(1-\varepsilon)-\lambda_2\delta_1N_1+\delta_2N_2-C_2<0$, and $C_3-\delta_3N_3<0$, i.e., under the following conditions, namely, the LSI's total benefits from KS cooperation exceed its costs, the LSP's benefits from non-participation in KS cooperation are higher than those achievable through participation, and the benefits of the government's KS incentive measures exceed their costs, the system will stabilize at (1, 0, 1). In this situation, as the LSP finds that the cost of participating in KS cooperation exceeds all the

TABLE 2 Local stability analysis.

Equilibrium point	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3	Symbol
(0, 0, 0)	$\delta_1 N_1 - C_1$	$\delta_2 N_2 - C_2$	$-C_3$	(+,+,−)
(0, 0, 1)	$C_3 + \delta_1 N_1 - C_1$	$C_3 + \delta_2 N_2 - C_2$	C_3	(+,+,+)
(0, 1, 0)	$Q\theta\sigma\varepsilon + \lambda_1\delta_2 N_2 + \delta_1 N_1 - C_1$	$C_2 - \delta_2 N_2$	$\delta_3 N_3 - C_3$	(±,−,+)
(0, 1, 1)	$\omega C_3 + Q\theta\sigma\varepsilon + \lambda_1\delta_2 N_2 + \delta_1 N_1 - C_1$	$C_2 - \delta_2 N_2 - C_3$	$C_3 - \delta_3 N_3$	(±,−,−)
(1, 0, 0)	$C_1 - \delta_1 N_1$	$Q\theta\sigma(1-\varepsilon) - \lambda_2\delta_1 N_1 + \delta_2 N_2 - C_2$	$\delta_3 N_3 - C_3$	(−,±,+)
(1, 0, 1)	$C_1 - \delta_1 N_1 - C_3$	$(1-\varepsilon)C_3 + Q\theta\sigma(1-\varepsilon) - \lambda_2\delta_1 N_1 + \delta_2 N_2 - C_2$	$C_3 - \delta_3 N_3$	(−,±,−)
(1, 1, 0)	$C_1 + \lambda_1\delta_2 N_2 - \delta_1 N_1 - Q\theta\sigma\varepsilon$	$C_2 + \lambda_2\delta_1 N_1 - \delta_2 N_2 - Q\theta\sigma(1-\varepsilon)$	$\delta_3 N_3 - C_3$	(±,±,+)
(1, 1, 1)	$C_1 + \lambda_1\delta_2 N_2 - \delta_1 N_1 - Q\theta\sigma\varepsilon - \omega C_3$	$C_2 + \lambda_2\delta_1 N_1 - \delta_2 N_2 - Q\theta\sigma(1-\varepsilon) - (1-\omega)C_3$	$C_3 - \delta_3 N_3$	(−,−,−)

benefits it can derive, it tends to opt out of KS (i.e., y approaches 0). However, for the LSI, the benefits of KS significantly outweigh the combined costs of participation and any potential subsidies received. At the same time, the government observes that the benefits of the incentives it provides for KS outweigh the associated costs, prompting the continued implementation of such policies. The overall system's evolutionary trends will eventually lead to (1, 0, 1).

Scenario 3: When $C_1 + \lambda_1\delta_2 N_2 - \delta_1 N_1 - Q\theta\sigma\varepsilon - \omega C_3 < 0$, $C_2 + \lambda_2\delta_1 N_1 - \delta_2 N_2 - Q\theta\sigma(1-\varepsilon) - (1-\omega)C_3 < 0$, and $C_3 - \delta_3 N_3 < 0$, it indicates that the LSI and LSP gain greater benefits from jointly participating in KS cooperation than they would without it. Additionally, the government finds that its KS incentive measures yield returns that exceed their costs. This suggests that all three parties are inclined to adopt KS cooperation and the corresponding incentive policies. In this case, the system evolves toward a state where all participants pursue active KS strategies, moving toward the state (1, 1, 1). As the LSI and LSP recognize that mutual KS cooperation delivers higher overall returns, they become more willing to engage in this mutually beneficial relationship. The government also notes that its KS incentive policies not only encourage more cooperative behavior but also produce net benefits that surpass the costs. Consequently, considering the interests of all stakeholders and the outcomes of cost–benefit analysis, the entire system moves toward a stable state (1, 1, 1), where every participant actively engages in KS cooperation, achieving a win–win outcome.

3 Evolutionary game simulation analysis

To verify the conclusions of the above evolutionary game analysis, this paper uses MATLAB for numerical simulations to examine how parameter changes affect the system's evolutionary path. Guided by economic assumptions and empirical judgments, parameters are assigned based on studies by [21, 22] and expert experience. Stability analysis of the equilibrium points across scenarios further explores the tripartite game's evolutionary trends and model validity, while sensitivity analysis of the key parameters intuitively identifies the factors influencing strategy evolution and parameter sensitivities in logistics service supply chain knowledge sharing.

3.1 Numerical analysis of the stability of the ideal equilibrium point

Scenario 1: When $\omega C_3 + Q\theta\sigma\varepsilon + \lambda_1\delta_2 N_2 + \delta_1 N_1 - C_1 < 0$, $C_2 - \delta_2 N_2 - C_3 < 0$, and $C_3 - \delta_3 N_3 < 0$, the system evolves toward the state (0, 1, 1). The logistics service integrator will eventually adopt a strategy of not participating in knowledge-sharing cooperation, and the logistics service provider will tend to choose knowledge sharing as its long-term stable strategy; meanwhile, the government, in pursuit of maximizing its own interests, will implement knowledge-sharing incentive subsidy policies. To further verify these theoretical deductions, simulations are conducted with the following parameters: $C_1 = 15$, $C_2 = 34$, $\delta_1 = 3$, $N_1 = 6$, $\delta_2 = 4$, $N_2 = 5$, $\delta_3 = 2$, $N_3 = 5$, $Q = 5$, $\theta = 2$, $\sigma = 2$, $\varepsilon = 0.6$, $\lambda_1 = 0.4$, $\lambda_2 = 0.6$, $C_3 = 4$, and $\omega = 0.5$. The results, as shown in Figure 1, are consistent with the previous conclusions.

Scenario 2: When $C_1 - \delta_1 N_1 - C_3 < 0$, $(1-\omega)C_3 + Q\theta\sigma(1-\varepsilon) - \lambda_2\delta_1 N_1 + \delta_2 N_2 - C_2 < 0$, and $C_3 - \delta_3 N_3 < 0$, the system evolves toward the state (1, 0, 1). This means that the logistics service integrator will eventually tend to choose knowledge-sharing cooperation as its stable strategy. Conversely, the logistics service provider will decide not to participate in knowledge-sharing cooperation after a series of long-term decisions; the government, to maximize its own interests, will implement knowledge-sharing incentive subsidy measures. To further verify these theoretical deductions, simulations are conducted with the following parameters: $C_1 = 10$, $C_2 = 20$, $\delta_1 = 3$, $N_1 = 4$, $\delta_2 = 4$, $N_2 = 3$, $\delta_3 = 2$, $N_3 = 4$, $Q = 5$, $\theta = 2$, $\sigma = 2$, $\varepsilon = 0.6$, $\lambda_1 = 0.4$, $\lambda_2 = 0.6$, $C_3 = 4$, and $\omega = 0.5$. The results, as shown in Figure 2, are consistent with the previous conclusions.

Scenario 3: When $C_1 + \lambda_1\delta_2 N_2 - \delta_1 N_1 - Q\theta\sigma\varepsilon - \omega C_3 < 0$, $C_2 + \lambda_2\delta_1 N_1 - \delta_2 N_2 - Q\theta\sigma(1-\varepsilon) - (1-\omega)C_3 < 0$, and $C_3 - \delta_3 N_3 < 0$, the system reaches the stable state (1, 1, 1). This indicates that after long-term decision-making games, both the logistics service integrator and the logistics service provider will choose knowledge sharing as their final stable strategy. Meanwhile, to maximize its own

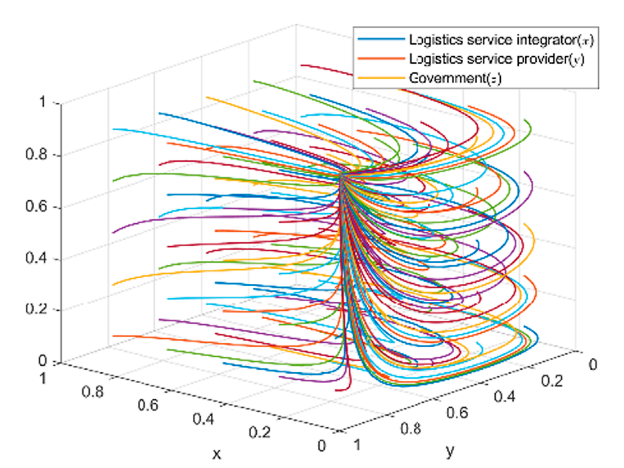

FIGURE 1
Scenario 1 simulation.

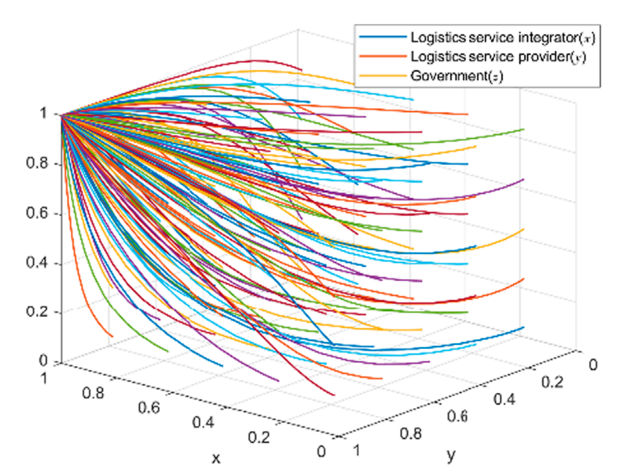

FIGURE 3
Scenario 3 simulation.

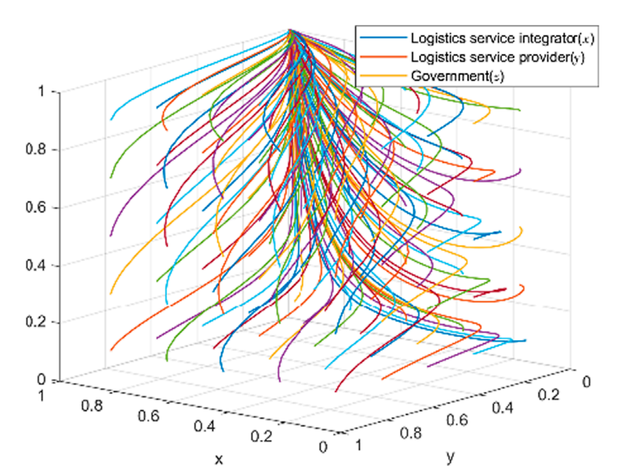

FIGURE 2
Scenario 2 simulation.

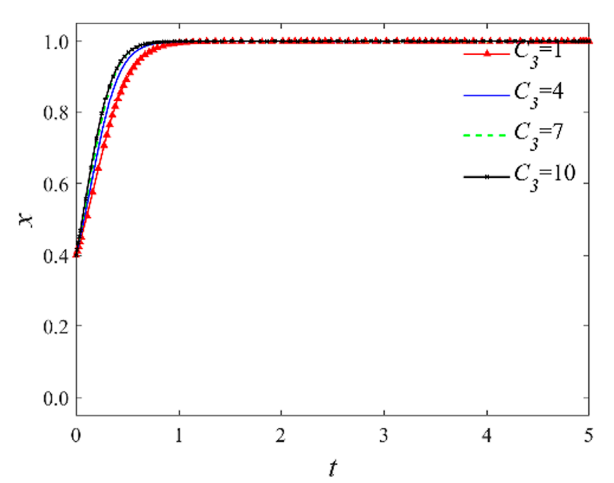

FIGURE 4
Influence of government incentives and subsidies on the x-axis.

interests, the government will tend to implement incentive subsidy policies to promote knowledge sharing. To further verify these theoretical deductions, simulations are conducted with the following parameters: $C_1 = 16$, $C_2 = 14$, $\delta_1 = 3$, $N_1 = 6$, $\delta_2 = 4$, $N_2 = 5$, $\delta_3 = 2$, $N_3 = 6$, $Q = 5$, $\theta = 2$, $\sigma = 2$, $\varepsilon = 0.6$, $\lambda_1 = 0.4$, $\lambda_2 = 0.6$, $C_3 = 5$, and $\omega = 0.5$. The results, as shown in Figure 3 are consistent with the previous conclusions.

For parameter assignment: Referring to the application of the Shapley value method in logistics collaboration, integrators typically have a distribution ratio exceeding 50% because of their roles in resource integration and risk underwriting. To satisfy $Q\theta\sigma\varepsilon - \lambda_1\delta_2 N_2 > 0$ (ensuring positive returns for integrators), ε is set as 0.6. Furthermore, considering the development stage of knowledge-sharing technologies in the logistics industry, technical maturity is graded on a five-point scale, so θ is assigned the value 2. Finally, according to the research team's survey, integrators—because of their leading role in collaboration—usually receive 40%–60% of the subsidies. For model simplification, $\omega = 0.5$ is adopted to reflect the balanced game between integrators and providers in subsidy

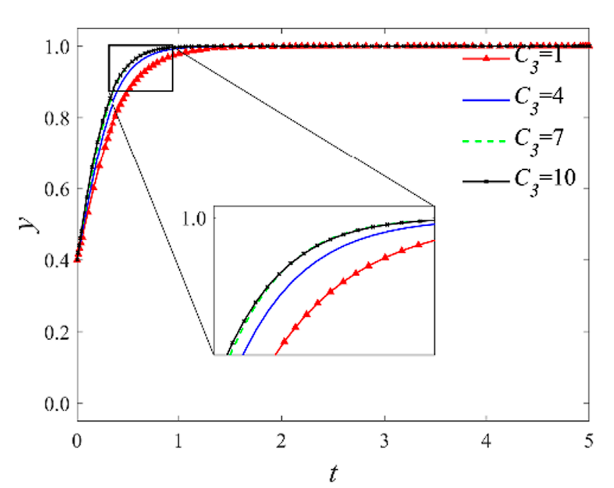

FIGURE 5
Influence of government incentives and subsidies on the y-axis.

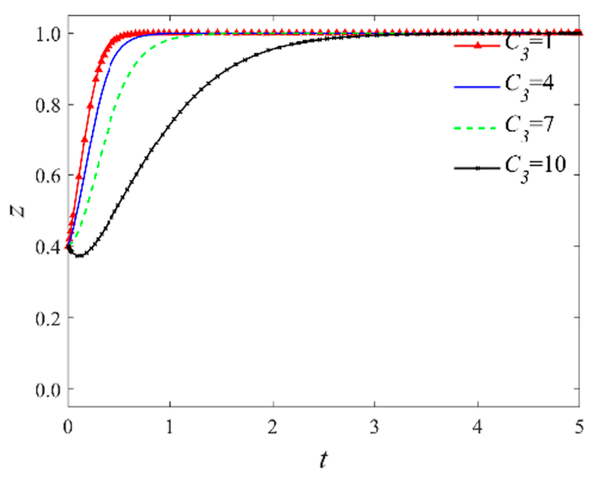

FIGURE 6
Influence of government incentives and subsidies on the z-axis.

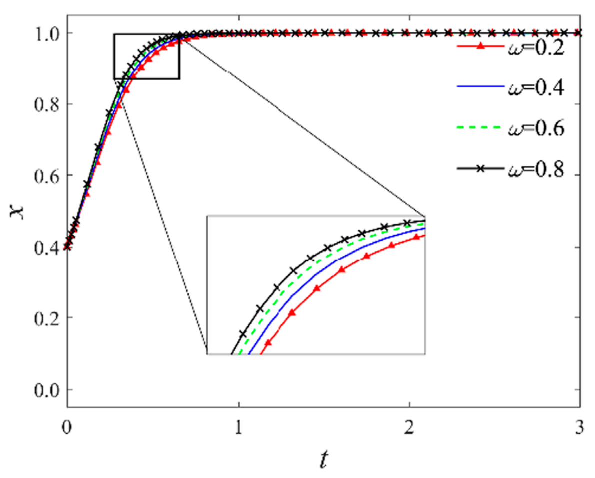

FIGURE 7
Influence of the government incentive subsidy distribution ratio on the x-axis.

distribution. These parameter assignments satisfy the conditions for the (1, 1, 1) scenario. In addition, the initial values of $x, y, and z$ start at 0.1, with a fixed step size of 0.2, and random simulations are conducted from 0.1 to 0.9. The evolutionary process of the tripartite evolutionary game strategies under this scenario is illustrated in the figure.

3.2 Numerical analysis of parameter sensitivity

To more intuitively analyze the key factors influencing the strategy evolution of various subjects and the sensitivity of the related parameters during the knowledge-sharing process in the logistics service supply chain, the following section conducts a sensitivity analysis with the evolutionary stable point (1, 1, 1) as the initial scenario.

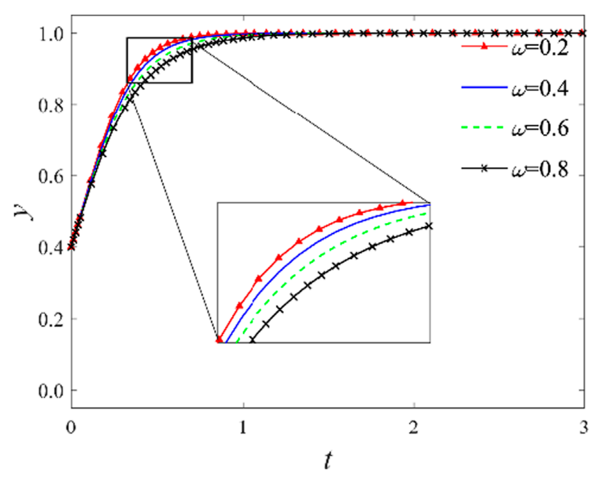

FIGURE 8
Influence of the government incentive subsidy distribution ratio on the y-axis.

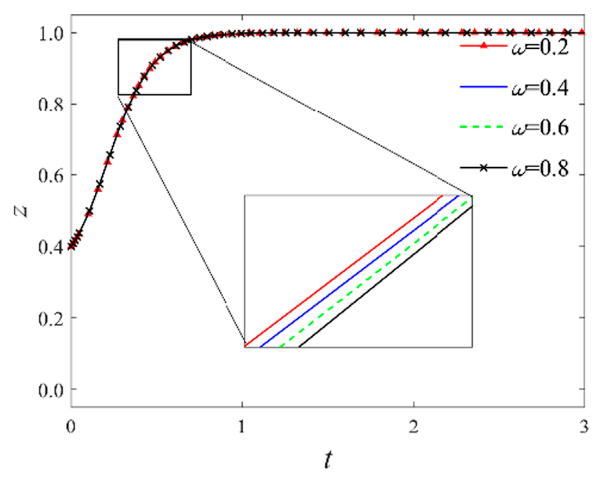

FIGURE 9
Influence of the government incentive subsidy distribution ratio on the z-axis.

3.2.1 Impact of government incentive subsidies

As indicated by the previous analysis, the amount of incentive subsidies C_3 provided by the government exerts a significant influence on whether the government itself, logistics service integrators, and providers choose to engage in knowledge-sharing cooperation. Therefore, under the assumption that all other conditions remain unchanged, experiments are conducted by setting the government's knowledge-sharing cooperation incentive subsidies C_3 to 1, 4, 7, and 10, respectively, with the system evolution, results shown in the Figures 4–6. In the current scenario, an increase in the government's incentive subsidy amount accelerates the convergence of the strategy probabilities of integrators and providers to 1; while the government's own strategy probability still converges to 1, its convergence rate slows down as the subsidy amount increases. This indicates that the government, as a crucial incentive subject in the logistics service supply chain, shares part

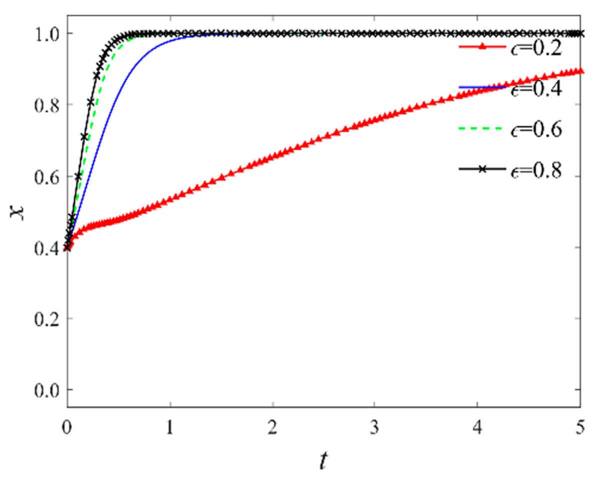

FIGURE 10
Impact of co-creation value income distribution on the x-axis.

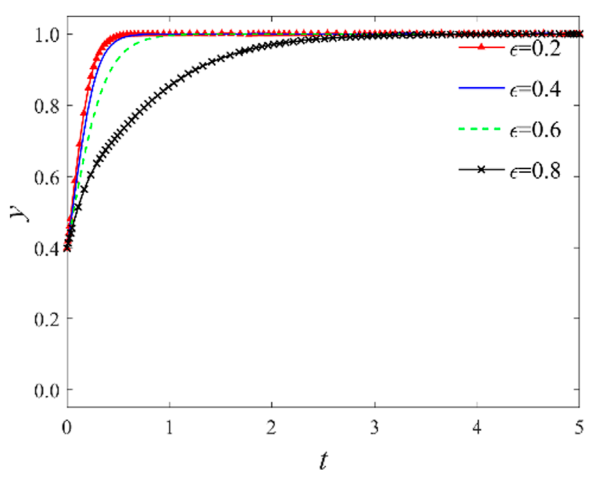

FIGURE 11
Impact of co-creation value income distribution on the y-axis.

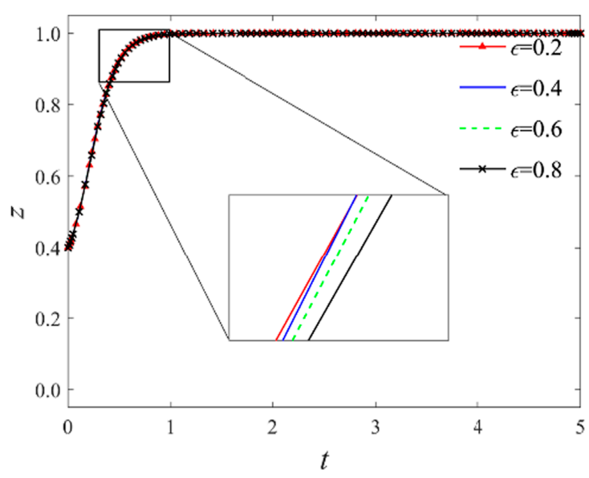

FIGURE 12
Impact of co-creation value income distribution on the z-axis.

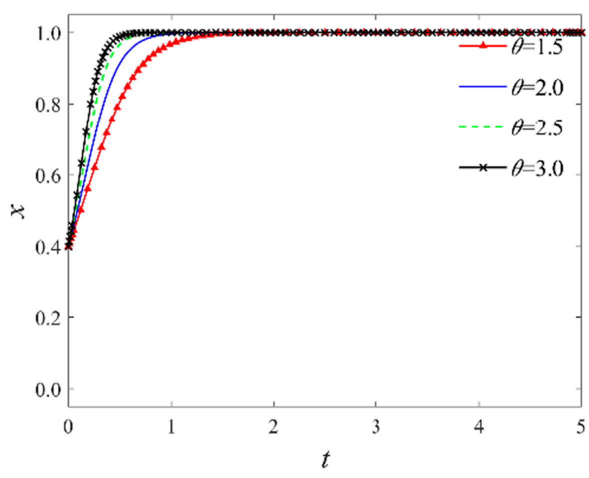

FIGURE 13
Impact of maturity of knowledge-sharing technology distribution on the x-axis.

of the knowledge-sharing costs for the integrators and providers through incentive subsidies, enabling both parties to gain more benefits from sharing. Moreover, higher government subsidies enhance the willingness of the logistics service supply chain to actively engage in knowledge-sharing cooperation. However, the government must also appropriately consider costs when providing incentive subsidies to avoid excessive subsidies that could disrupt the virtuous cycle.

3.2.2 Impact of the distribution ratio of government incentive subsidies

The aforementioned analysis shows that the distribution ratio of government incentive subsidies significantly affects knowledge-sharing cooperation decisions between integrators and providers. With other conditions held constant, an investigation of the distribution ratio ω set to 0.2, 0.4, 0.6, and 0.8 reveals that as ω increases, both parties' strategy choices converge to 1 at an accelerating rate. This indicates that a reasonable subsidy distribution range effectively promotes revenue growth, development, and smooth knowledge-sharing cooperation. Exceeding this range may cause distrust and unfairness, thus weakening cooperation willingness despite substantial knowledge-sharing benefits. The results of the system evolution are shown in Figures 7–9.

3.2.3 Impact of the distribution ratio of shared value benefits

As shown in previous analyses, the method of distributing co-created value benefits significantly influences knowledge-sharing cooperation decisions between logistics service integrators and providers. With all other conditions held constant, the distribution ratio ε of co-created value benefits is set to 0.2, 0.4, 0.6, and 0.8 for investigation. As this ratio increases, the rate at which

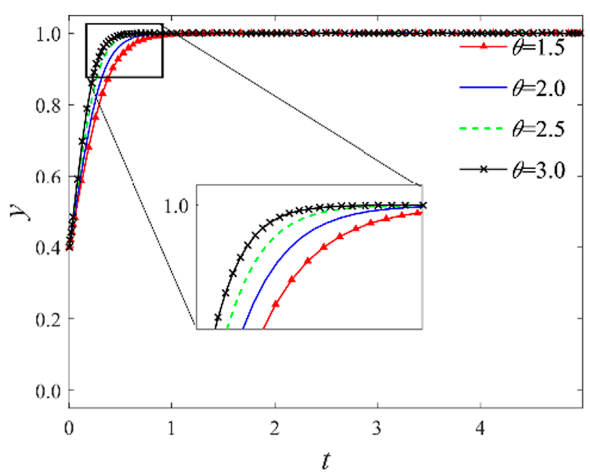

FIGURE 14
Impact of maturity of knowledge-sharing technology distribution on the y-axis.

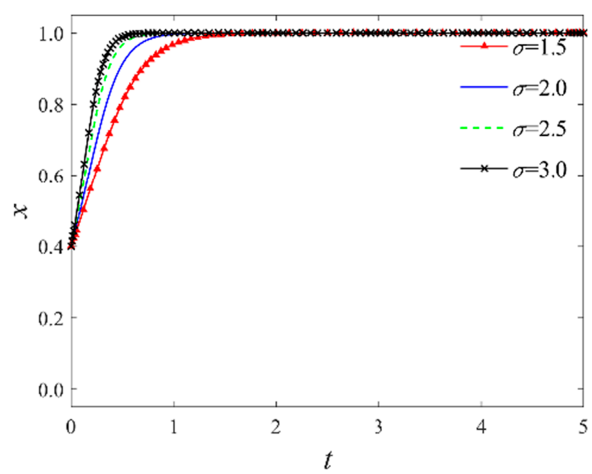

FIGURE 16
Impact of the trust level among logistics enterprise distribution on the x-axis.

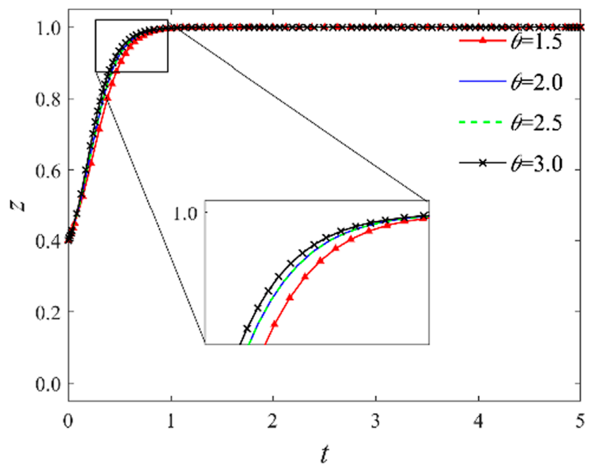

FIGURE 15
Impact of maturity of knowledge-sharing technology distribution on the z-axis.

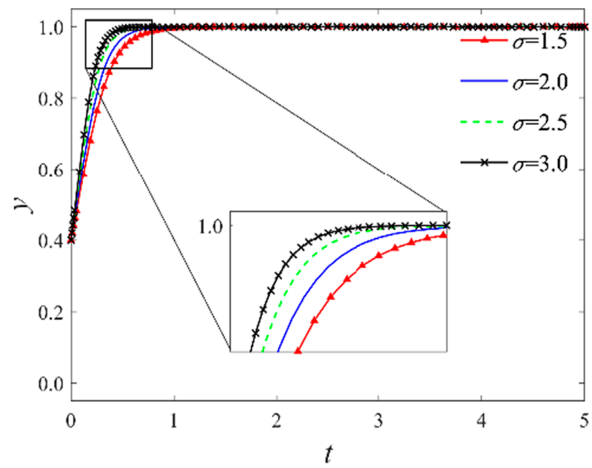

FIGURE 17
Impact of the trust level among logistics enterprise distribution on the y-axis.

the logistics service integrator's strategy probability converges to 1 accelerates gradually, while that of the logistics service provider slows down. This study finds that when the distribution of co-created value benefits falls between 0.5 and 0.8, both parties are more inclined to choose knowledge-sharing cooperation after long-term gaming, with the specific evolutionary path shown in Figures 10–12. However, once the distribution ratio exceeds this range (i.e., 0.5–0.8), the irrationality of benefit distribution may induce a sense of unfairness between enterprises, thereby fostering a mindset that is incompatible with cooperation. In such cases, even with high subsidies or substantial benefits from knowledge sharing, the willingness of both parties to participate in cooperation will be negatively affected.

3.2.4 Impact of industry knowledge-sharing technology maturity

The parameter θ is assigned values of 1.5, 2.0, 2.5, and 3.0 to analyze its influence on system evolution. As shown in Figures 13–15, the strategy choices of both logistics service integrators and providers converge to 1 with an accelerating rate as the maturity of industry knowledge-sharing technology increases. This indicates that higher maturity of knowledge-sharing technology in the industry leads to lower costs and greater convenience for knowledge sharing among subjects, thereby incentivizing them to engage in knowledge-sharing cooperation and achieve value co-creation. Since the maturity of industry knowledge-sharing technology has little impact on the

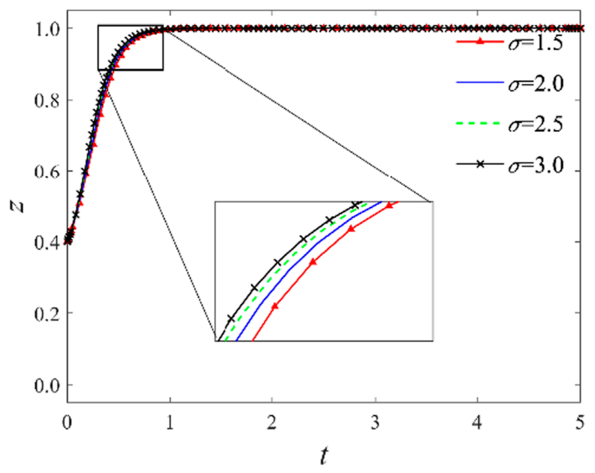

FIGURE 18
Impact of the trust level among logistics enterprise distribution on the z-axis.

government's strategy choices, no further analysis of it is provided in this study.

3.2.5 Impact of trust level among logistics enterprises

The parameter σ is assigned values of 1.5, 2.0, 2.5, and 3.0 to analyze its influence on system evolution. As shown in Figures 16–18, the strategy choices of both logistics service integrators and providers converge to 1 with an accelerating rate as the trust level among logistics enterprises increases. This indicates that a higher level of trust among enterprises in the industry reduces the resistance to knowledge sharing, making all parties more inclined to engage in cooperative knowledge sharing and thus achieving a win–win situation.

4 Conclusions and recommendations

4.1 Research conclusions

This study centers on knowledge-sharing collaboration within logistics service supply chains. Guided by the assumption of bounded rationality, it establishes a tripartite game analysis framework incorporating government participation and profoundly examines the impact pathways through which core variables—such as policy incentives, inter-enterprise mechanisms for distributing knowledge-sharing gains, and subsidy allocation—influence system evolution. Based on the research findings, strategic recommendations for advancing knowledge sharing are put forward based on three dimensions: logistics service integrators, providers, and government authorities. These recommendations aim to enhance the overall performance of the supply chain and promote the realization of industrial collaborative value. The key research conclusions of this paper are as follows:

1. When selecting partners, integrators should prioritize the potential providers' knowledge-sharing costs, knowledge quality, cooperation environment, and expected benefits, preferring those with high enthusiasm, quality resources, strong reputations, and proven cooperation records. For industry-wide value co-creation, matching with providers on value co-creation benefits is critical.
2. Government incentive subsidies effectively boost cooperation willingness between integrators and providers, but their impact depends on the mechanism design. Rational subsidies stimulate cooperation, while unfair or flawed designs may trigger refusal due to perceived inequity. Appropriate policies also promote fair benefit distribution within the supply chain, thus enhancing the overall competitiveness.

4.2 Countermeasure recommendations

1. As core hubs, logistics service integrators should address knowledge-sharing barriers from technical constraints by building high-caliber technical teams, optimizing collaborative innovation mechanisms to enhance algorithmic and intelligent decision-making capabilities, and improving data analysis efficiency. They should establish efficient data interconnection platforms to integrate the user behavior and service process data for real-time and accurate demand response and share non-core data to strengthen the providers' collaboration willingness, thereby fostering symbiotic relationships and enhancing full-chain service capacity and market responsiveness.
2. Logistics service providers, as key executors, need to overcome limited data analysis capabilities by establishing systematic data management frameworks, integrating full-chain logistics data, and adopting intelligent analysis tools to strengthen data-driven decision making. They should proactively connect upstream and downstream nodes to build collaborative networks, advance dual-cycle mechanisms, and improve marginal benefits via digital transformation. Leveraging the policy and market resources, providers should accelerate intelligent facility development with government subsidies and industrial funds, establish information synchronization platforms, enhance inter-partner trust, and promote joint data development and industry-wide value co-creation.
3. Governments, as supervisors and guides, should establish multi-level incentive mechanisms (e.g., tax incentives and credit rating linkage) to foster enterprise collaboration in data sharing and resource integration, with dynamic adjustments ensuring policy foresight. They should upgrade governance structures by building cross-departmental, cross-level information platforms, formulating unified data exchange standards and conflict-mediation mechanisms, and integrating blockchain and smart contracts to ensure transparency and transaction security. Additionally, governments should improve credit evaluation systems,

integrate enterprise credit with industry access, strengthen irregularity tracing, introduce third-party audits, and build a credit-based market environment to drive high-quality logistics development.

Data availability statement

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

Author contributions

GZ: Conceptualization, Methodology, Writing – review and editing. JZ: Conceptualization, Methodology, Writing – review and editing. KZ: Writing – review and editing, Methodology.

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Conflict of interest

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

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