IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received August 21, 2020, accepted October 11, 2020, date of publication October 19, 2020, date of current version October 28, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3031929

Research on Logistics Service Supply Chain Information Sharing Mechanism in the Belt and Road Initiative

GUOHAO LI, QI ZHANG, ZHENGYU BAI, AND PERVAIZ SABEEH

School of Management, Jiangsu University, Zhenjiang 212013, China

Corresponding author: Qi Zhang (2221810027@stmail.ujs.edu.cn)

This work was supported in part by the National Natural Science Foundation of China under Grant 71771127, and in part by the Jiangsu Graduate Practice Innovation Fund Project under Grant SJCX20_1398.

ABSTRACT In the context of the Belt and Road Initiative (BRI), demand in informatization and coordinated logistics services is playing increasing attention to the frequent international trade transactions. Several authors have proposed models about supply chain information sharing focused on product supply chain to analyze the factors affecting the level of corporate information sharing and the relationship between the level of information sharing and corporate performance, etc. However, little is available to study on the decision-making issues of corporate information sharing in the service supply chain. This paper aims to reveal the possible impact of the government's infrastructure construction investment and government incentives on the logistics service supply chain in the logistics service supply chain under this theme. This paper constructs an evolutionary game model to explore the dynamic selection process of corporate information co-strategy, the logistics service supply chain composed of functional logistics service provider (FLSP) and logistics service integrator (LSI) taked as the research object. Numerical experiments show that the additional revenue of information sharing, revenue distributing coefficient, information sharing risk coefficient and the speculative income coefficient are closely to the probability of gamers' choosing information sharing; moreover, investment in government infrastructure construction is conducive to improving the initial willingness of logistics companies to implement information sharing in which the government's incentives for corporate information sharing behavior are directly proportional to the probability of logistics companies choosing information sharing. We discuss the practical implications of the proposed model, and the wider implications for improving the level of international logistics cooperation and the high-quality development of logistics enterprise informatization under the BRI.

INDEX TERMS Logistics service supply chain, information sharing mechanism, belt and road initiative, evolutionary game.

I. INTRODUCTION

In 2013, President Xi of China proposed the cooperative initiative of building the "New Silk Road Economic Belt" and "21st Century Maritime Silk Road" respectively [1]. These proposals are officially termed as the One Belt and One Road initiative (OBOR) or the Belt and Road initiative (BRI). It aims to use the ancient Chinese "Silk Road" civilization symbols to actively develop economic partnerships with countries along the route to establish trade and infrastructure networks connecting Asia, Europe and Africa [2], and build several economies cooperation corridors, upgrading ports, railway networks and other infrastructure in more than 60 countries [3] to accelerate global economic growth [4], [5]. The proposal and implementation of BRI is conducive to exploring the market potential of various countries, creating demand and employment, and promoting investment and consumption in various countries [6] in which broader and deeper regional cooperation emerges [7]. As the largest international cooperation platform, the BRI has triggered lots of great achievements in interconnection, tamping the long-term stable development of the world economy, achieving global rebalancing, and creating new regional cooperation [8].

As a consequence of increasing demand in services from international economic cooperation and national economy development, the logistics industry plays an important role in

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

the Belt and Road Initiative. It's not surprising that the BRI has created opportunities and challenges for the development of the logistics industry in China and the countries along the route, accelerating the construction of transportation infrastructure in countries along the route [9]. With interconnection and win-win cooperation as the core, accelerating the establishment of logistics information networks, innovating logistics business models, and promoting information sharing and coordinated development between upstream and downstream enterprises in the logistics industry is essential to meet the growing demand for trade under this theme [10]. Thus Information sharing issues that arise in exchanges and cooperation arise. To solve information sharing problems, we explore the impact of government subsidies, income distribution, and other factors on the choice of logistics enterprise information sharing strategies in the logistics service supply chain in the context of BRI.

As we all know, Logistics service supply chain (LSSC) is an important form of international freight, centered on the cooperation of logistics service capabilities [11], [12]. The chain is provided by the functional logistics service provider (FLSP), logistics service integrators (LSI), and manufacturers or retailers [13], having the advantage of integrating logistics resources and promoting cooperation between supply and demand in the international freight business. Information sharing refers to the exchange and transmission of information between different organizations in the course of transactions or cooperation. Scholars believe information sharing in LSSC can reduce the risks caused by information asymmetry, such as mitigating the bullwhip effect and reducing logistics costs (*e.g.* [14]–[16]). From information sharing, it can promote the reconstruction of information to greatly enhance its knowledge value, form a knowledge reserve, and enhance the actual operating performance of the supply chain effectively. However, logistics companies also need to invest certain costs and face the business risks that information sharing may bring. Then, when companies in the logistics service supply chain share information, do government infrastructure construction, cost compensation, and other supplements have any impact on the behavior of each company? By the way, how factors such as revenue distribution and trust risk affect the behavior of providers and integrators? How to formulate government incentive strategies and revenue distribution strategies to improve the efficiency of information sharing between providers and integrators?

To the best of our knowledge, this is the first analytical study that focuses on the dynamic selection problem of information sharing decision-making when enterprises cooperate in the international logistics service supply chain system under the BRI. It should be noted here that all kinds of logistics companies come from different regions and serve different fields. Some of them are multinational logistics companies themselves, and some are service providers of international companies. In the process of information sharing decision-making, factors such as the partner's strategic choice and the profit distribution decision of the leading enterprise in LSSC may change the node enterprise's strategic choice. For instance, information-sharing decisions may change when a freight company cooperates with a logistics service integrator, aware of the integrator's information sharing degree and profit distribution coefficient. Our numerical study reveals that in the logistics service supply chain, the improvement of one party's initial willingness to share information will improve the probability of the other party choosing information sharing strategy.

By the same token, "The Belt and Road Initiative" is China's most ambitious international economic initiative. The initiative aims to stimulate the economic development and international cooperation of the regions along the route, bringing not only opportunities but also challenges to many sectors of the regional economy, especially the logistics industry. Due to various measures taken by the governments of countries along the Belt and Road, the choice of information sharing strategies for companies in LSSC has become diversified. Existing research on the cooperation between logistics companies and supply chains usually focuses on manufacturers' outsourcing strategies and principal-agent theory, little attention is paid to the BRI and its impact on logistics service mode. Under the BRI, the logistics service supply chain requires to break down information barriers, integrate resources, and achieve economies of scale.

In this paper, we take into consideration the impact of different factors such as investment in infrastructure construction by governments of countries along the route and government cost subsidies on the dynamic evolution process of the strategy choices of both gamers in the game innovatively. We adopt the evolutionary game theory to analyze the dynamic evolution of information sharing strategy choices between providers and integrators in the logistics service supply chain. Moreover, numerical experiments are used to emphasize analytical changes in government infrastructure investment, cost subsidies, information sharing risks and other factors under the BRI, changes in the behavioral strategies of suppliers and integrators, and the impact on enterprise information sharing and cooperation in LSSC. Furthermore, combined with the actual situation, we put forward countermeasures and suggestions for enterprises in LSSC to develop information sharing strategies to improve the overall benefits between suppliers and integrators

The rest of the paper is organized as follows: A section with the relevant theories of logistics service supply chain and information sharing is provided next. Our evolutionary game model of information sharing between integrators and providers in the logistics service supply chain is presented in Section 3. Section 4 is devoted to an analysis for the evolutionary stability of evolutionary game models. We discuss the influence of different parameter changes on the dynamic evolution process by means of numerical simulation study in Section 5. Section 6 concludes our work with directions for future research and some management insights.

II. LITERATURE REVIEW

A. LOGISTICS SERVICE SUPPLY CHAIN

Due to the development of the Internet and communication technologies, innovating logistics industry service models and integrating freight resources have become easier. In the course of the ''One Belt One Road'' initiative, the fast-growing global economy and frequent international trade have put forward higher requirements for logistics service levels [17]. In order to adapt to the increasingly fierce competitive environment and meet the diversified demands of customers, the logistics industry attaches much more importance to informatization and coordinated development. Logistics service integrators (LSI) and functional logistics service providers (FLSP) have adopted alliances and integration to form a logistics service supply chain [11], [18]. The basic structure of LSSC is a functional logistics service provider → logistics service integrator → manufacturing and retail enterprise model (*e.g.* [13]& [19]). Regarding the definition of the logistics service supply chain, Schmidt and Wilhelm [20] and others designed a logistics service supply chain structure model from three aspects of strategy, tactics and operation, including procurement, transportation, distribution, and other functions; Persson and Virum [21] and others distinguished the logistics supply chain model based on the supplier's assets; Hertz and Alfredsson [22] divided logistics companies into logistics service providers, logistics service developers, customer adaptors and customer developers based on the types of services provided and customer satisfaction, and they constitute the entire logistics service business system, their interactive communication makes the chain function normally; Choy *et al.* [11] deemed that integrators as the center of integrating logistics service supply chain integrate the resources of both supply and demand by providing diversified services, and improved the efficiency of freight matching. The effectiveness, authenticity, and quantity of information matter much for the full role-playing of the integrators. Obviously, the integrator not only requires taking technology to establish a good information management system, but also needs the participation of logistics service providers and customers those who need logistics services. Through timely and accurate information sharing, it helps integrators understand customer needs and effectively allocate orders according to the provider's business characteristics.

Overall, from the extant literature, there is no doubt that the research on the logistics service supply chain mainly focuses on supplier performance evaluation and influencing factors (*e.g.* [23]–[26]), supplier selection [27], coordination mechanism [28], [29]) and order allocation (*e.g.* [18], [30], [31]) and so on. Besides, Liu *et al.* [32] considered the uncertainty of the supplier's operating time in a mass customization service environment, and established a multi-objective planning and scheduling model for the logistics service supply chain; Zhong *et al.* [33], based on the Stackelberg game theory, studied the profit distribution scheme of the revenue sharing contract, the research results show that a reasonable income distribution scheme is conducive to the cooperation between logistics service supply chain partners so as to achieve profitable growth and a win-win situation. Liu *et al.* [34] studied the LSSC scheduling problem and believed that the ability to provide customized services at the expense of public services through reasonable scheduling has become a key factor in determining LSSC competition. In existing studies, the importance of cooperation and coordination, resource allocation, and revenue sharing factors among various enterprises in LSSC to improving the essence of LSSC service level has arose the scholars' attention. However, there is a lack of relevant research on the impact of information sharing mechanism on the efficiency of LSSC services.

B. ENTERPRISE INFORMATION SHARING

Each link in the business activities of an enterprise will generate corresponding information, which in turn can promote the development of the enterprise. It is a unique and very important resource owned by the enterprise, which can bring additional benefits beyond the business activities for the enterprise. Information sublimates value in sharing, At the same time, the rapid development of modern information technology, which is characterized by communication technology and computer technology, builds a bridge for information sharing. Scholars have basically the same definition of information sharing: Lee *et al.* [16] believed that information sharing is a collaborative plan, in this plan, upstream and downstream enterprises achieve a win-win situation by sharing market demand forecasts and inventory levels related to supply chain operations; Avalos [35] believed that information sharing is a process of communication and interaction between two or more parties in information provision and information acquisition; Khan *et al.* [36] proposed that information sharing is an information-based cooperation method adopted by enterprises in the supply chain to reduce supply chain operating costs and achieve efficient supply chain operations; Dubey *et al.* [37] pointed out that information sharing is a development supply chain agility, adaptability, and coordination of information exchange methods. It can be seen that information sharing is particularly important in strengthening enterprise cooperation and achieving multi-party win-win results. Thus, it can be seen that information sharing is particularly important in strengthening enterprise cooperation to achieve a multi-party win-win situation. It can enhance the communication and interaction among enterprises in the supply chain, help enterprises timely understand market changes and customer needs, and realize the complementary advantages among enterprises, so as to reduce the overall operating cost and form economies of scale.

Information plays an increasingly important role in enterprise competition. Many scholars have conducted quantitative research on the problem of information sharing between enterprises. Chatfield *et al.* [38] through a numerical simulation comparison study found that information sharing reduces 50% of the bullwhip effect of manufacturers; Fiala [39] found that information sharing can smooth the flow of information, strengthen strategic partnerships in the supply chain, and improve the overall performance of the supply chain; Chandra *et al.* [40] further pointed out that information sharing plays a key role in facilitating and guaranteeing the implementation of supply chain management strategic decisions; in general, information sharing can effectively reduce the influence of uncertain factors in the supply chain operation process, avoid information distortion, and improve the overall market competitiveness of the supply chain. Albert *et al.* [41] conducted research on the contract and information sharing involved in two competitive supply chains, and the results showed that information sharing can play an advantageous role in supply chain competition, and information sharing can significantly increase supply chain value. Ha *et al.* [41] studied the problem of vertical information sharing in a competitive supply chain, and Arya *et al.* [42] studied the outsourcing of information to competitors to reformulate "make or buy" decision making. Zhang [43] studied the measures to promote the vertical sharing of demand information under the condition of horizontal competition. Most of the existing researches on supply chain information sharing focus on product supply chain, however, few researches concern about enterprise information sharing in service supply chain. Due to the characteristics of logistics service, such as non-storability and timeliness, which are different from products, the existing research cannot be fully applied to the research on the information sharing mechanism of logistics service supply chain, and specific research needs to be carried out according to the characteristics of LSSC and its composition structure.

C. EVOLUTIONARY GAME

Evolutionary game theory originated from the game analysis of the conflict and cooperative behavior of animals and plants by genetic biologists such as Fisher. It is assumed that the game players are not completely rational individuals, and the strategy is constantly changed until the evolutionary equilibrium in the continuous trial process, which is more in line with the actual environment compared with the traditional theory [44]. The concepts of evolutionary stability strategy (ESS) [45] and replicate dynamic equation (RD) [46] constitute the core basic concept of evolutionary game theory, respectively characterizing the final stable state of system evolution and the dynamic process of converging to this stable state [47].

Evolutionary game theory has been widely used in the fields of economics, finance, and society. Among these fields, there are many researches on information sharing mechanism among groups. Lin and Gaozhi [48] used the evolutionary game model to analyze the dynamic evolution process of network organization information sharing; Jian *et al.* [49] used evolutionary game theory to analyze the evolution of information sharing behavior among supply chain network companies with different penalties and information sharing risk costs. Research shows that increasing fines and controlling cost sharing risks can increase supply chain information sharing networks possibility and shorten the time of information sharing; based on the theory of evolutionary game theory, Shen *et al.* [50] established a game model for online health community members' information sharing. Research shows that online health community managers need to increase the income coefficient of information sharing, reduce the cost of information sharing risks, and promote online community patients' sustainable information sharing; Yi *et al.* [51] constructed an evolutionary game model to study the impact of factors such as the degree of information system, information absorption capacity, information system cost, incentive coefficient, penalty coefficient, risk coefficient and synergy coefficient on the decision-making of enterprise information sharing in forest product supply chain.

Currently, research on information sharing mechanisms is mostly focused on information sharing between product supply chains and community members. Many scholars have studied the impact of subsidies, incentives, supervision, contracts and other factors on supply chain coordination. But little attention is paid to information sharing between upstream and downstream enterprises in the service supply chain. Different from the existing research, from the perspective of improving the overall benefits of the logistics service supply chain, we have studied the evolution process of enterprise information sharing behavior in LSSC; and based on existing research, the influence of factors such as government participation, revenue distribution, and information sharing risks on the stability of system evolution is analyzed.

III. INFORMATION SHARING AND MODEL INTEGRATION OF LOGISTICS SERVICE SUPPLY CHAIN

A. INFORMATION SHARING IN LOGISTICS SERVICE SUPPLY CHAIN

The logistics service supply chain takes customer needs as the starting point and logistics service integrators as the center [52]. Through resource integration and communication interaction, the logistics service demand side and the supply side are formed into a system to form a comprehensive logistics that can respond to changes in business scale. Logistics service integrators rely on their advanced logistics information systems and rich logistics management experience to integrate functional logistics companies and customer needs [53], design logistics services for customers, and distribute orders to multiple logistics service providers, according to the demand. Enterprises in the supply and demand chain have realized information sharing, cooperative decision-making, risk sharing, and common development in the process of cooperation and competition [54]. In the LSSC system, the integrator has functions such as logistics resource development, logistics resource procurement, logistics system integration, logistics service activity supervision and control, and integrated value-added service provision. The functional logistics service providers refer to logistics companies that carry out traditional businesses such as transportation, distribution, and warehousing. Their business types are relatively single, and they are suppliers of integrators.

The customer group refers to the customer with logistics service needs, such as product supply chain of the manufacturing enterprise accompanying suppliers and distributors, or it can be a separate customer enterprise. It can be seen that integrators, suppliers, and customer groups in LSSC are closely connected, forming a whole of coordination and cooperation and value creation. Integrators are the key nodes connecting the entire supply chain. They must accurately grasp the upstream and downstream information resources of LSSC, understand market demand and service capabilities, in order to realize the scale benefits of LSSC.

The strategic partnership between the integrator and the client company is a long-term logistics service procurement/supplier relationship [33]. The integrator's information integration and planning capabilities are combined with the provider's professional service capabilities, complementing each other's strengths and forming a stable two-echelon structure. The two-echelon structure is shown in Figure 1.

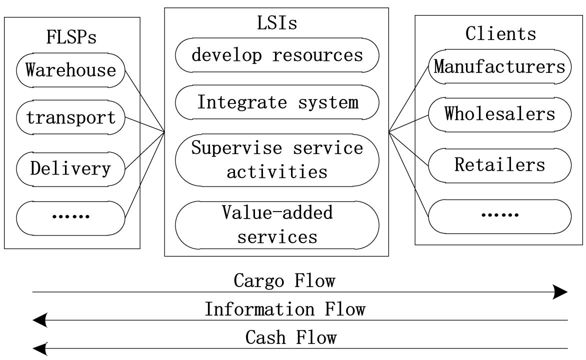

FIGURE 1. The model of two-echelon logistics service supply chain.

LSSC is inseparable from information exchange and interaction, and information sharing in LSSC is conducive to realizing value-added and creating economies of scale. Research by scholars has shown that the factors that affect enterprise information sharing include information sharing cost, sharing risks, changes in the external environment, information technology level, revenue distribution and so on (*e.g.* [36]–[39]). Formulating a reasonable revenue distribution plan and information sharing strategy to achieve cooperation between logistics service supply chain partners is conducive to achieving a win-win situation for all partners' profit growth [33]. Therefore, adequate and effective information communication and exchange between logistics service supply chain subsystem enterprises is an important means to ensure the stable and efficient operation of the logistics service supply chain. In the context of the Belt and Road Initiative, information sharing among LSSC companies is particularly important for achieving efficient and excellent interconnection and trade growth and is conducive to promoting the development of the international logistics system.

B. PROBLEM DESCRIPTION AND ASSUMPTIONS

Through the above analysis of the factors that affect information sharing, it can be seen that whether the enterprise in LSSC chooses information sharing will consider many factors. In the process of transaction and cooperation, both parties have been in a state of repeated games, and neither party is completely rational [44]. Affected by internal factors such as ability and knowledge level, the optimal strategy cannot be found at the beginning of the game. It's necessary to learn and adjust in the repeated game process, and constantly change the strategy to achieve a stable equilibrium [55]. Based on the above analysis, the logistics service level of information sharing in the supply chain system depends on the system of each node enterprises in the information technology into the hardware infrastructure investment and human resources. In the context of digital economy, the logistics information sharing platform based on Internet technology is an important carrier and technical support to improve the level of LSSC information sharing. Under the BRI, we establish a logistics game supply chain evolution game model, with government infrastructure construction, enterprise information technology level, information sharing risks, and information sharing costs taken into consideration, and some hypothesis are as follows:

Hypothesis 1: The main players of the game are the logistics service integration commercial 1 and the functional logistics service provider commercial 2. Both parties have two strategies to choose from: (1) reluctant to share information with enterprise partners E_e; (2) willing to share information with enterprise partners E_c. The probability of gamer 1 choosing information sharing strategy is x, and the probability of choosing information non-sharing strategy is $1 - x$; the probability of gamer 2 choosing information sharing strategy is y, and the probability of choosing information non-sharing strategy is $1 - y$, where $(0 \leq x \leq 1, 0 \leq y \leq 1)$. Subscript 1 indicates logistics service integrators, subscript 2 indicates logistics service providers; superscript e indicates information sharing, and subscript c indicates that information non-sharing.

Hypothesis 2: The two sides of the game have a long-term cooperative relationship. Even if they choose information non-sharing, the cooperative relationship will continue. In the process of cooperation, when the gamers choose information non-sharing, the normal conventional obtained by completing the logistics business is R_i $(\mathrm{i} = 1, 2)$.

Hypothesis 3: When the gamers choose the information sharing strategy, the additional revenue obtained by the two parties in cooperation to complete the customer order is M. The integrator and the provider will be allocated a proportion of the additional revenue obtained, in which the integrator's revenue distribution coefficient is λ, the provider's revenue distribution coefficient is $1 - \lambda$.

Hypothesis 4: The governments of the countries along the Belt and Road actively responded to the BRI. They increased infrastructure construction, developed logistics information sharing platforms, and accelerated the construction of 5G base stations, which was conducive to improving the additional revenue during information sharing, and the coefficient of influence of government investment on additional revenue

TABLE 1. Payoff matrix.

integrators	providers	
	information sharing (y)	information non-sharing ($1-y$)
information sharing (x)	$\prod_1^{ee}$, $\prod_2^{ee}$	$\prod_1^{ec}$, $\prod_2^{ec}$
information non-sharing ($1-x$)	$\prod_1^{ce}$, $\prod_2^{ce}$	$\prod_1^{cc}$, $\prod_2^{cc}$

is δ, where ($\delta > 1$). In order to promote international economic and trade exchanges, strengthen the integration of logistics resource information, and encourage logistics companies to implement information sharing, the government will encourage information sharing behaviors, the incentive is α.

Hypothesis 5: While information sharing brings extra benefits to enterprises, it also needs to spend a certain cost, such as the cost of information technology efforts, information technology transfer, upgrade, replacement of network platform construction and maintenance, and other information technology input costs, the information technology input costs is S_i (i $= 1, 2$); When carrying out information communication and exchange, logistics enterprises must invest information communication costs, such as human resources and material resources, the information exchange input costs is Q_i ($i = 1, 2$), the degree of information sharing and information quality depends on the cost of information exchange.

Hypothesis 6: When enterprises share their private information, there are various potential risks, such as business information leakage and moral hazard, which leads to an increase in the company's operating costs. Use θ to denote the risk cost of information sharing, in general $0 < \theta < 0.5$. Because when the risk of information sharing is too high, companies tend to choose to avoid information sharing. When one party chooses information sharing and the other party chooses information non-sharing, the party that chooses information non-sharing will receive speculative income, the speculative income coefficient is K, at the same time, the size of speculative income is also related to Q_i.

C. THE MODEL BUILDING

As mentioned above, the two types of enterprises, game main body 1 and game main body 2, choose from the same strategic space $\{E_e, E_c\}$, and the revenue of both parties depend on the strategic choices of both parties, as shown in Table 1.

Each payoff expression in Table 1 is as follows:

$$\prod_1^{ee} = R_1 + \lambda M\delta + \alpha - S_1 - Q_1$$
$$\prod_2^{ee} = R_2 + (1-\lambda)M\delta + \alpha - S_2 - Q_2$$
$$\prod_1^{ec} = R_1 + \alpha - S_1 - (1+\theta)Q_1$$
$$\prod_2^{ec} = R_2 + KQ_1$$
$$\prod_1^{ce} = R_1 + KQ_2$$
$$\prod_2^{ce} = R_2 + \alpha - S_2 - (1+\theta)Q_2$$
$$\prod_1^{cc} = R_1$$
$$\prod_2^{cc} = R_2$$

IV. THE MODEL ANALYZING

Based on Table 1, the expected revenue of the integrator's choice of information sharing strategy, the expected revenue of the information non-sharing strategy and the average expected revenue are:

$$U_1^e = y\lambda M\delta + R_1 + \alpha - S_1 - (1+\theta)Q_1 + y\theta Q_1$$
$$U_1^c = yKQ_2 + R_1$$
$$U_1 = xU_1^e + (1-x)U_1^c$$

Similarly, the expected revenue of the provider's choice of information sharing strategy, the expected revenue of the information non-sharing strategy and the average expected revenue are:

$$U_2^e = y(1-\lambda)M\delta + R_2 + \alpha - S_2 - (1+\theta)Q_2 + y\theta Q_2$$
$$U_2^c = yKQ_1 + R_2$$
$$U_2 = yU_2^e + (1-y)U_2^c$$

According to the Malthusian dynamic equation, the growth rate of the strategy is equal to its relative fitness. As long as the individual fitness of the strategy is higher than the average fitness of the group, then this strategy will grow (Liu *et al.*, 2011). The replicate dynamic equation for integrators information sharing can be obtained as follows:

$$G(x) = \frac{dx}{dt} = x(U_1^e - U_1) = x(1-x)[y(\lambda M\delta - KQ_2 + \theta Q_1) + \alpha - S_1 - (1+\theta)Q_1]$$

The replicate dynamic equation for providers information sharing is as follows:

$$F(y) = \frac{dy}{dt} = y(U_2^e - U_2) = y(1-y)[x((1-\lambda)M\delta - KQ_1 + \theta Q_2) + \alpha - S_1 - (1+\theta)Q_1]$$

According to the replicate dynamic equations of integrators and providers, the two-dimensional power system L composed of integrators and providers is obtained as follows:

$$L = \begin{cases} G(x) = x(1-x)[y(\lambda M\delta - KQ_2 + \theta Q_1) \\ \qquad + \alpha - S_1 - (1+\theta)Q_1] \\ F(y) = y(1-y)[x((1-\lambda)M\delta - KQ_1 + \theta Q_2) \\ \qquad + \alpha - S_2 - (1+\theta)Q_2] \end{cases}$$

For convenience, let $A = -KQ_2+\theta Q_1$, $B = S_1+(1+\theta)Q_1$, $C = -KQ_1 + \theta Q_2$, $D = S_2 + (1 + \theta)Q_2$, $T = \lambda M\delta$, let $x_0 = \frac{S_2+(1+\theta)Q_2-\alpha}{(1-\lambda)M\delta-KQ_1+\theta Q_2}$, $y_0 = \frac{S_1+(1+\theta)Q_1-\alpha}{\lambda M\delta-KQ_2+\theta Q_1}$.

A. STABILITY ANALYSIS OF INTEGRATOR'S EVOLUTION STRATEGY

According to the stability theorem of differential equations in evolutionary games, to make a strategy in a stable state, the probability x of choosing this strategy must be satisfied separately:

$$G(x) = 0, \quad G'(x) < 0$$

At this time, it can be divided into three situations:

(1) When $y = y_0$ $(0 < y_0 < 1)$, then get $G(x) = 0$, at this time, the integrators adopt any probability of ''information sharing'' strategy is stable.

(2) When $y > y_0$, when $\lambda M\delta - KQ_2 + \theta Q_1 > 0$, then $G'(0) > 0, G'(1) < 0$, at this time $x = 1$ is stable state; when $\lambda M\delta - KQ_2 + \theta Q_1 < 0$, then $G'(0) < 0$, $G'(1) > 0$, at this time $x = 0$ is stable state.

(3) When $y < y_0$, when $\lambda M\delta - KQ_2 + \theta Q_1 > 0$, then $G'(0) < 0, G'(1) > 0$, at this time $x = 0$ is a stable state; when $\lambda M\delta - KQ_2 + \theta Q_1 < 0$, then $G'(0) > 0$, $G'(1) < 0$, at this time $x = 1$ is a stable state.

B. STABILITY ANALYSIS OF PROVIDER'S EVOLUTION STRATEGY

According to the replicate dynamic equation of the provider's information sharing strategy, it can also be divided into three situations:

(1) When $x = x_0$ $(0 < x_0 < 1)$, then get $F(y) = 0$, the providers adopt any probability of ''information sharing'' strategy is stable.

(2) When $x > x_0$, when $(1 - \lambda)M\delta - KQ_1 + \theta Q_2 > 0$, then $F'(0) > 0, F'(1) < 0$, at this time $y = 1$ is a stable state; when $(1 - \lambda)M\delta - KQ_1 + \theta Q_2 < 0$, then $F'(0) < 0, F'(1) > 0$, at this time $y = 0$ is a stable state.

(3) When $x < x_0$, when $(1 - \lambda)M\delta - KQ_1 + \theta Q_2 > 0$, then $F'(0) < 0, F'(1) > 0$, at this time $y = 0$ is a stable state; when $(1 - \lambda)M\delta - KQ_1 + \theta Q_2 < 0$, then $F'(0) > 0, F'(1) < 0$, at this time $y = 1$ is a stable state.

C. STABILITY ANALYSIS OF SYSTEM EVOLUTION STRATEGY

The local equilibrium point of the replicate dynamic equation solved by the replicate dynamic equation is not necessarily the evolutionary stability strategy of the system. The stability of the evolutionary equilibrium point of the system can be analyzed according to the method proposed by Friedman [56], it is obtained by analyzing the local stability of the Jacobi matrix of the system. The Jacobi matrix of integrators and providers is J, as shown at the bottom of the page.

When the matrix is satisfied $Det(J) > 0$, $Tr(J) < 0$, the local equilibrium point will become the evolutionary stability strategy (ESS). Through calculation, the values of $Det(J)$ and $Tr(J)$ at multiple equilibrium points can be obtained as shown in the following table.

By analyzing the determinant of the Jacobi matrix and the stability of the evolution system of the trace, six situations are got as follows.

(1) Situation 1, when $\alpha - B < 0$, $\alpha - D < 0$, the evolutionary stability strategy (ESS) of the system is E_1 (0, 0). It can be seen that when the government has the little force of incentive to the information sharing behavior of logistics enterprises and cannot compensate for the information technology input costs, information exchange inputs costs and the costs of the sharing risk faced by enterprises in implementing information sharing strategies, both integrators and providers choose information non-sharing. The evolution path diagram in this situation is shown in Figure 2(a).

(2) Situation 2, when $T+A+\alpha-B < 0, \alpha-D > 0$, the evolutionary stability strategy (ESS) of the system is E_2 (0, 1). In this case, the integrators choose information non-sharing, and the providers choose information sharing. $T+A+\alpha-B < 0$ is $\lambda M\delta-KQ_2+\alpha-S_1-Q_1 < 0$, and the $\lambda M\delta+\alpha-S_1-Q_1$ means that when both the integrator and the provider choose information sharing, the difference between the additional revenue distributed by the integrator and the government incentive subsidy and the cost of their information sharing is the total revenue from information sharing; KQ_2 means that when the provider chooses information sharing and the integrator chooses information non-sharing, the speculative income the integrator gains from the provider information sharing. $T + A + \alpha - B < 0$ means that when the provider chooses information sharing, the revenue of the integrator for information sharing is less than the speculative income obtained when the information non-sharing, so when the provider chooses information sharing, the integrator tend to choose information non-sharing; $\alpha - D > 0$ shows that the government's incentive amount for information sharing behavior is greater than the provider's information sharing technical input costs, information exchange input cost, and sharing risk. Therefore, regardless of the integrator's choice strategy, the provider chooses information sharing.

$$J = \begin{pmatrix} \frac{\partial G(x)}{\partial x} & \frac{\partial G(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{pmatrix} = \begin{pmatrix} (1-2x)[y(\lambda M\delta + A) + \alpha - B] & x(1-x)(\lambda M\delta + A) \\ y(1-y)((1-\lambda)M\delta + C) & (1-2y)[x((1-\lambda)M\delta + C) + \alpha - D] \end{pmatrix}$$

TABLE 2. Det(J) and Tr(J) of each equilibrium point in the dynamic evolution system.

ESS	$Det(J)$	$Tr(J)$
$E_1(0,0)$	$(\alpha-B)(\alpha-D)$	$(\alpha-B)+(\alpha-D)$
$E_2(0,1)$	$-(T+A+\alpha-B)(\alpha-D)$	$(T+A+\alpha-B)-(\alpha-D)$
$E_3(1,0)$	$-(\alpha-B)(M\delta-T+C+\alpha-D)$	$-(\alpha-B)+(M\delta-T+C+\alpha-D)$
$E_1(1,1)$	$(T+A+\alpha-B)(M\delta-T+C+\alpha-D)$	$-(T+A+\alpha-B)-(M\delta-T+C+\alpha-D)$
$E_5(x_0,y_0)$	$(\alpha-B)(D-\alpha)(M\delta-T+C+\alpha-D)$ $(T+A+\alpha-B)/[(M\delta-T+C)(T+A)]$	0

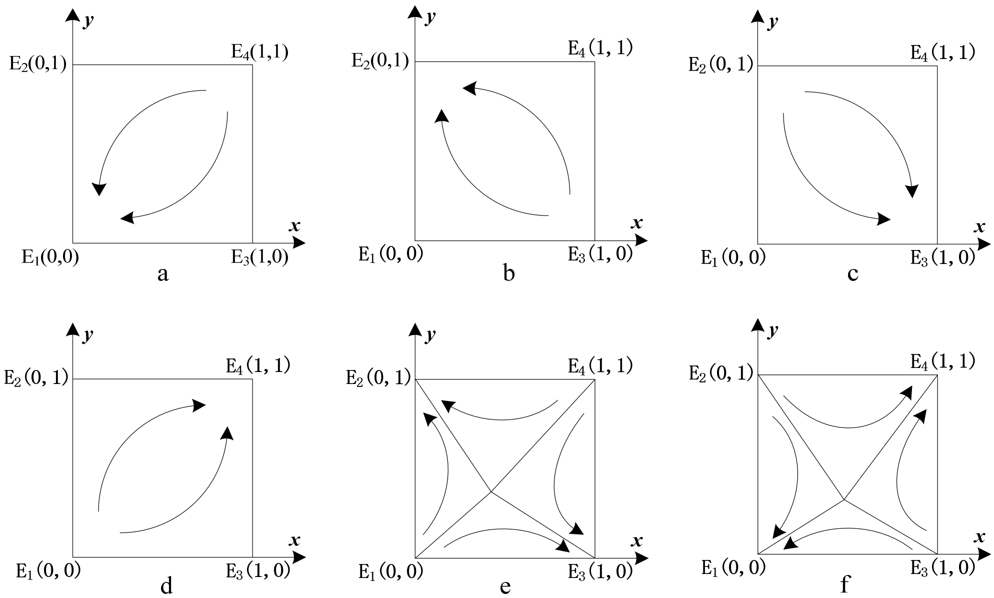

FIGURE 2. System evolution path diagram.

The evolution path diagram in this situation is shown in Figure 2(b).

(3) Situation 3, when $M\delta - T + C + \alpha - D < 0$, $\alpha - B > 0$, the evolutionary stability strategy (ESS) of the system is E_3 (1, 0). Under this situation, the integrators choose information sharing, and the providers choose information non-sharing. $\alpha - B > 0$ means that the government's incentive for information sharing is greater than the sum of the cost of integrators' information sharing and the risk of sharing. At this time, no matter what strategy the providers choose, the integrators will choose information sharing; $M\delta - T + C + \alpha - D < 0$ is $(1-\lambda)M\delta + \alpha - KQ_1 - S_2 - Q_2 < 0$, which means that when both the integrator and the provider choose information sharing, the difference between the additional revenue obtained by the provider and the cost of government incentives to supplement and share the information, that is, the total benefit of information sharing; $-KQ_1$ means that when the integrator is sharing information and the provider is information non-sharing, the provider's speculative income from the provider information sharing. $-KQ_1$ indicates that the profit of the provider when sharing information is less than the speculative income obtained when the information non-sharing, so when the integrator chooses information sharing, the provider will choose information non-sharing. The evolution path diagram in this situation is shown in Figure 2(c).

(4) Situation 4, when $T + A + \alpha - B > 0$, $M\delta - T + C + \alpha - D > 0$, the evolutionary stability strategy (ESS) of system is E_4 (1, 1). Under this situation, both integrators and providers choose information sharing. $T + A + \alpha - B > 0$ is $\lambda M\delta - KQ_2 + \alpha - S_1 - Q_1 > 0$, which shows that the revenue of integrators when sharing information is greater than the speculative income obtained when information non-sharing, so when providers choose information sharing, integrators tend to choose information sharing. Similarly, $M\delta - T + C + \alpha - D > 0$ shows that the revenue of the provider when sharing information is greater than the speculative income obtained when chooses information non-sharing, so when the integrator chooses information sharing, the provider also tends to choose information sharing. The evolution path diagram in this situation is shown in Figure 2(d).

(5) Situation 5, when $0 < \alpha - B < -T - A$ and $0 < \alpha - D < T - M\delta - C$, the evolutionary stability strategy (ESS) of the system is E_2 (0, 1) or E_3 (1, 0). This situation shows, when the force of government's incentives

for information sharing are strong and higher than the information technology input cost, information exchange input cost and information sharing risk cost paid by integrators and providers for information sharing, the enterprise's strategy choice depends on the additional revenue obtained when the two parties are sharing information. For integrators, when the additional revenue from distribution and the total revenue from government incentive compensation is less than the total cost of information sharing, the integrator will choose the information non-sharing strategy; similarly, for the provider, when the total revenue of the provider's distribution of additional revenue and government incentive subsidies is less than the total cost of its information sharing, the provider will choose information non-sharing strategy. The evolution path diagram in this situation is shown in Figure 2(e).

(6) Situation 6, when $-T - A < \alpha - B < 0$ and $T - M\delta - C < \alpha - D < 0$, the evolutionary stability strategy (ESS) of the system is E_1 (0, 0) or E_4 (1, 1). This situation shows, when the force of government's incentives for information sharing are little and lower than the information technology input cost, information exchange input cost and information sharing risk cost paid by integrators and providers for information sharing, the enterprise's strategy choice depends on the additional revenue obtained when the two parties information sharing. For integrators, when the additional revenue from distribution and the total revenue from government incentive compensation is more than the total cost of information sharing, the integrator will choose the information sharing strategy, otherwise, choose information non-sharing strategy; similarly, for the provider, when the total revenue of the provider's distribution of additional revenue and government incentive subsidies is more than the total cost of its information sharing, the provider will choose information sharing strategy, otherwise, choose information non-sharing strategy. The evolution path diagram in this situation is shown in Figure 2(f).

D. INFLUENCE OF PARAMETER CHANGES ON THE EVOLUTION RESULTS IN SITUATION SIX

For situation 6, when $-T-A < \alpha-B < 0$ and $T-M\delta-C < \alpha - D < 0$, the evolutionary stability strategy (ESS) of the system is E_1 (0, 0) or E_4 (1, 1), the evolutionary results are not unique. It can be seen from Figure 6 that the final evolution state of the system is related to the area of the regional AECB and the regional AECO. Suppose the area of AECB is H_1 and the area of AECO is H_2, then it can be seen, the greater the area H_1 and the smaller the area H_2, the greater the probability that the system will converge to the stable point E_4 (1, 1), that is, the higher the probability that the system will tend to (information sharing, information sharing).

Therefore, in this case, the analysis of the influencing factors of the system evolution and stability results can be transformed into the analysis of the area H_1 of AECB or the area H_2 of AECO. For the convenience of calculation, the area H_2 of AECO in the analysis area is selected to be affected by the change of parameters.

$$H_2 = \frac{1}{2}\left(\frac{S_2 + (1+\theta)Q_2 - \alpha}{(1-\lambda)M\delta - KQ_1 + \theta Q_2} + \frac{S_1 + (1+\theta)Q_1 - \alpha}{\lambda M\delta - KQ_2 + \theta Q_1}\right)$$

It can be seen from the above formula that the parameters that affect the size of H_1 are S_1, S_2, Q_1, Q_2, θ, λ,, α, M, δ, K. Find the partial derivative of each parameter for H_1, and further analyze the influence of each parameter on the size of H_1. For convenience, the partial derivative formulas are as follows:

$$\frac{\partial H_2}{\partial S_1} = \frac{1}{2}\left(\frac{1}{A+T}\right) > 0$$
$$\frac{\partial H_2}{\partial S_2} = \frac{1}{2}\left(\frac{1}{M\delta - T + C}\right) > 0$$
$$\frac{\partial H_2}{\partial Q_1} = \frac{1}{2}\left[\frac{\theta+1}{A+T} - \frac{\theta(B-\alpha)}{(A+T)^2} + \frac{K(D-\alpha)}{(M\delta - T + C)^2}\right] > 0$$
$$\frac{\partial H_2}{\partial Q_2} = \frac{1}{2}\left[\frac{\theta+1}{M\delta - T + C} - \frac{\theta(D-\alpha)}{(M\delta - T + C)^2} + \frac{K(B-\alpha)}{(A+T)^2}\right] > 0$$
$$\frac{\partial H_2}{\partial \theta} = \frac{1}{2}\left[\frac{Q_1}{A+T} + \frac{Q_2}{M\delta - T + C} - \frac{Q_1\,(B-\alpha)}{(A+T)^2} - \frac{Q_2\,(D-\alpha)}{(M\delta - T + C)^2}\right] > 0$$
$$\frac{\partial H_2}{\partial \lambda} = \frac{M\delta(D-\alpha)}{(M\delta - T + C)^2} - \frac{M\delta(B-\alpha)}{(A+T)^2}$$
$$\frac{\partial H_2}{\partial \alpha} = -\frac{1}{M\delta - T + C} - \frac{1}{A+T} < 0$$
$$\frac{\partial H_2}{\partial \delta} = \frac{1}{2}\left[\frac{M(\lambda-1)(D-\alpha)}{(M\delta - T + C)^2} - \frac{M\lambda(B-\alpha)}{(A+T)^2}\right] < 0$$
$$\frac{\partial H_2}{\partial M} = \frac{1}{2}\left[\frac{\delta(\lambda-1)(D-\alpha)}{(M\delta - T + C)^2} - \frac{\delta\lambda(B-\alpha)}{(A+T)^2}\right] < 0$$
$$\frac{\partial H_2}{\partial K} = \frac{1}{2}\left[\frac{Q_1\,(D-\alpha)}{(M\delta - T + C)^2} + \frac{Q_2\,(B-\alpha)}{(A+T)^2}\right] > 0$$

(1) According to the above formula, $\partial H_2/\partial S_1 > 0$, $\partial H_2/\partial S_2 > 0$, $\partial H_2/\partial Q_1 > 0$, $\partial H_2/\partial Q_2 > 0$. It can be seen that the higher the information technology input costs and information exchange input costs between integrators and providers for information sharing, the less possibility the system tends to (information sharing, information sharing).

(2) According to the above formula, $\partial H_2/\partial \theta > 0$, the risk coefficient of information sharing between integrators and providers will have an impact on the evolution of the system. The higher the risk coefficient of information sharing, the less possibility the system will tend to (information sharing, information sharing).

(3) According to the above formula, the size of $\partial H_2/\partial \lambda$ cannot be judged. Therefore, the additional revenue distribution coefficient does not affect the system evolution of situation 6.

(4) According to the above formula, $\partial H_2/\partial \alpha < 0$, $\partial H_2/\partial \delta < 0$, $\partial H_2/\partial M < 0$. It can be seen that the higher the government's incentives for information sharing, the impact coefficient of the investment in government infrastructure

construction on additional revenue, and the higher the additional revenue when both parties choose information sharing, the greater the probability that the system will tend to (information sharing, information sharing). The government's incentives increase the revenue of integrators and providers when sharing information, the strong force of incentive will attract both parties to choose information sharing behaviors. At the same time, the government's investment in infrastructure construction provides good conditions for both parties to share information, which is conducive to improving the scale benefit of information sharing. Therefore, the government's investment in infrastructure construction has a positive incentive effect on information sharing behaviors. When the force of government's incentives are greater and the government's infrastructure construction investment is more complete, the motivation of information sharing between integrators and providers increases, and the total revenue of information sharing increases, thereby further increasing the probability of the system tending to (information sharing, information sharing).

(5) According to the above formula, $\partial H_2/\partial K > 0$. It can be seen that when one of the integrator and provider chooses information sharing, and the other party does not choose information sharing, the greater the speculative income of the party information non-sharing, the less probability the system will tend to (information sharing, information sharing). When the speculative income is large, the party that chooses information non-sharing is more willing to continue the information non-sharing behavior and maintain its profits through speculative income; and this speculative income damages the income of the party that chooses information sharing. This situation will reduce the probability of the other party sharing information, and eventually, the system will tend to (information non-sharing, information non-sharing).

V. NUMERICAL SIMULATION ANALYSIS

Logistics service integrators and logistics service providers are affected by various factors such as additional revenue, information sharing risks, government incentives, and input costs when choosing information sharing strategies. At the same time, due to the functional differences between integrators and providers in the logistics service supply chain system. The initial willingness of both parties to choose information sharing strategies is also different. This section further analyzes and discusses the evolution process of information sharing strategy selection between integrators and providers through numerical simulation, and analyzes the impact of different parameter changes on the dynamic evolution process.

In order to simulate the actual situation, combined with the field investigation, the parameter values in the game payment matrix are defined as follows: the additional revenue of information sharing of integrators and providers is $M = 4$ ten thousand. Since integrators mainly perform information matching and resource integration in the logistics service supply chain, revenue distributing coefficient of information sharing for integrators is $\lambda = 0.375$, and that for providers is $\lambda = 0.625$. Coefficient of impact of investment in government infrastructure construction on information sharing is $\delta = 2$. The government's incentive to corporate information sharing is $\alpha = 8$ ten thousand. Information technology input costs by integrators for information sharing is $S_1 = 3$ ten thousand, and the information exchange input costs is $Q_1 = 4$ ten thousand. Information technology input costs by providers for information sharing is $S_2 = 6$ ten thousand, and the information exchange input costs is $Q_2 = 2$ ten thousand. Information sharing risk coefficient of both parties is $\theta = 0.5$. One party chooses information sharing and the other party chooses information non-sharing, the speculative income coefficient of the party which chooses information non-sharing is $K = 1$.

1. The impact of the initial willingness of both parties to choose information sharing and the additional revenue of information sharing M on the evolution of the behavior strategies of each gamer. M takes 2, 4, 8 ten thousand respectively, then the corresponding game evolution results are shown in Figure 3-4.

According to Figure 3, the evolution of the integrator's behavior strategy is significantly affected by the additional revenue of information sharing. The increase in the integrator's initial willingness to choose information sharing accelerates the integrators' evolution in the direction of information sharing and reduces the evolution in the direction of information non-sharing speed. The specific impact process is as follows:

(1) When the additional revenue of information sharing is little ($M = 2$), the behavior of the integrator has nothing to do with the initial willingness size of information sharing between the two parties, and it has always evolved toward the direction of information non-sharing.

(2) When the additional revenue of information sharing is medium ($M = 4$). Firstly, when the initial willingness of providers to choose information sharing is low ($y = 0.2$), only integrators with the high initial willingness ($x = 0.8$) will evolve in the direction of the information sharing. Secondly, when the initial willingness of providers to choose information sharing is medium ($y = 0.5$), only integrators with the low initial willingness ($x = 0.2$) will evolve in the direction of information non-sharing. Thirdly, when the initial willingness of providers to choose information sharing is high ($y = 0.8$), all of the integrators will evolution in the direction of information sharing.

(3) When the additional revenue of information sharing is high ($M = 8$).The behavior of the integrator has nothing to do with the initial willingness of both parties to share information, and it has always evolved in the direction of information sharing.

According to Figure 4, it can be seen that the evolution process of providers is the same as the integrator's behavior strategy evolution process. The evolution of the provider's behavior strategy is significantly affected by additional revenue during information sharing. The increase in the initial willingness of the provider to share information accelerates the evolution of the provider towards information sharing

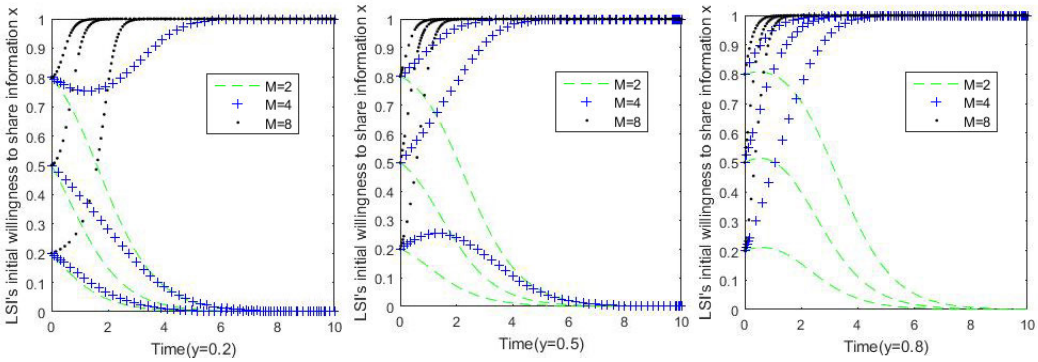

FIGURE 3. Effect of M and initial willingness on integrator's evolutionary results.

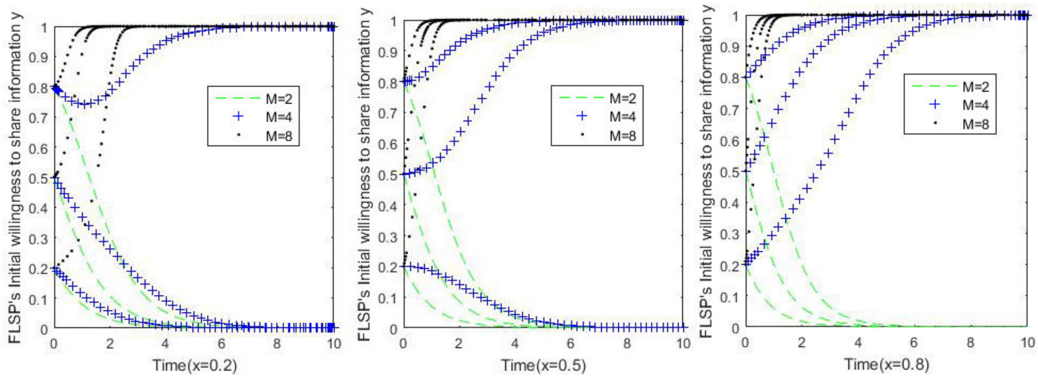

FIGURE 4. Effect of M and initial willingness on provider's evolutionary results.

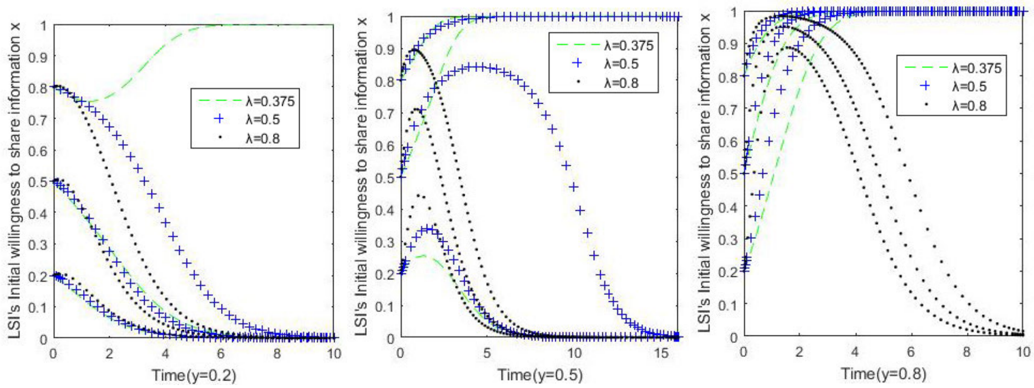

FIGURE 5. Effect of λ and initial willingness on integrator's evolutionary results.

and reduces the speed of evolution towards information non-sharing.

2. The impact of the initial willingness of both parties to choose information sharing and the revenue distributing coefficient of information sharing λ on the evolution of the behavior strategies of each gamer. λ takes 0.375, 0.5, 0.8 respectively, and then the corresponding game evolution results are shown in Figure 5-6.

It can be seen from Figure 5 that the increase in the revenue distributing coefficient of information sharing in the logistics service supply chain system has increased the probability and speed of the integrators' evolution towards information non-sharing, and reduced the speed of the integrators' evolution towards information sharing. The specific impact process is as follows:

(1) When the revenue distributing coefficient of information sharing is high ($\lambda = 0.8$), the behavior of the integrator has nothing to do with the initial willingness size of information sharing between the two parties, and it has always evolved toward the direction of information non-sharing.

IEEE Access

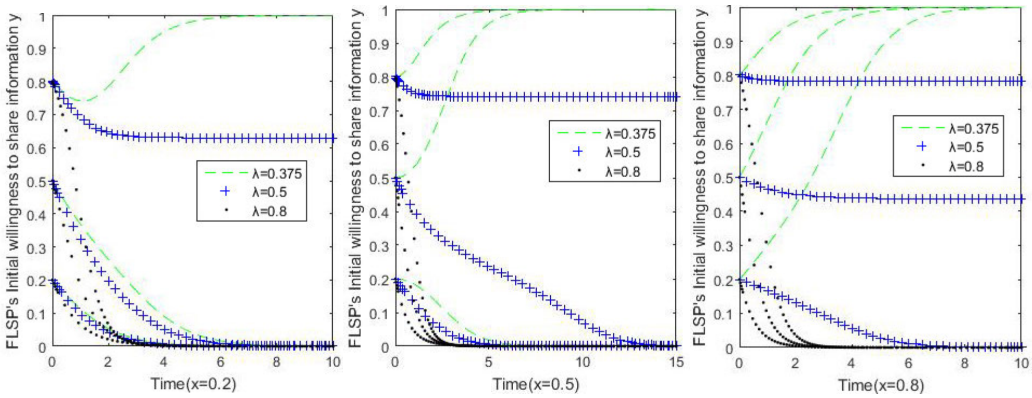

FIGURE 6. **Effect of λ and initial willingness on the provider's evolutionary results.**

(2) When the revenue distributing coefficient of information sharing is medium ($\lambda = 0.5$). Firstly, when the initial willingness of providers to choose information sharing is low ($y = 0.2$), all of the integrators will evolution in the direction of the information non-sharing. Secondly, when the initial willingness of providers to choose information sharing is medium ($y = 0.5$), only integrators with high initial willingness ($x = 0.8$) will evolution in the direction of information sharing. Thirdly, when the initial willingness of providers to choose information sharing is high ($y = 0.8$), all of the integrators will evolution in the direction of information sharing.

(3) When the revenue distributing coefficient of information sharing is low ($\lambda = 0.375$). Firstly, when the initial willingness of providers to choose information sharing is low ($y = 0.2$), only integrators with high initial willingness ($x = 0.8$) will evolution in the direction of the information sharing. Secondly, when the initial willingness of providers to choose information sharing is medium ($y = 0.5$), the integrators with medium or high initial willingness ($x = 0.5, 0.8$) will evolution in the direction of information sharing. Thirdly, when the initial willingness of providers to choose information sharing is high ($y = 0.8$), all of the integrators will evolution in the direction of information sharing.

It can be seen from Figure 6 that the increase in the profit distribution coefficient of information sharing in the logistics service supply chain increases the probability and speed of providers' evolution toward information non-sharing, and reduces the speed of integrators' evolution toward information sharing. The specific impact process is as follows:

(1) When the revenue distributing coefficient of information sharing is medium or high ($\lambda = 0.5, 0.8$), the behavior of the integrator has nothing to do with the initial willingness size of information sharing between the two parties, and it has always evolved toward the direction of information non-sharing.

(2) When the revenue distributing coefficient of information sharing is low ($\lambda = 0.375$). Firstly, when the initial willingness of integrators to choose information sharing is low ($x = 0.2$), only providers with high initial willingness ($y = 0.8$) will evolution in the direction of the information sharing. Secondly, when the initial willingness of integrators to choose information sharing is medium ($x = 0.5$), the providers with medium or high initial willingness ($y = 0.5, 0.8$) will evolution in the direction of information sharing. Thirdly, when the initial willingness of integrators to choose information sharing is high ($x = 0.8$), all of the providers will evolution in the direction of information sharing.

3. The impact of the initial willingness of both parties to choose information sharing and impact coefficient of investment in government infrastructure construction on additional revenue δ on the evolution of the behavior strategies of each gamer. δ takes 1.5, 2, 3 respectively, then the corresponding game evolution results are shown in Figure 7-8.

According to Figure 7, the integrator's behavior strategy is significantly affected by the initial willingness of both parties and the impact coefficient of investment in government infrastructure construction on additional revenue.

When the impact coefficient of investment in government infrastructure construction is low ($\delta = 1.5$), the integrators will evolution in the direction of the information non-sharing, and the lower the integrator's initial willingness to share information, the faster the evolution. When the impact coefficient of investment in government infrastructure construction is medium ($\delta = 2$), if the providers with medium or low initial willingness ($y = 0.2, 0.5$), only integrators with a high initial willingness ($x = 0.8$) will evolution in the direction of information sharing, and if the providers with a high initial willingness ($y = 0.8$), all of the integrators will evolution in the direction of information sharing. When the impact coefficient of investment in government infrastructure construction is high ($\delta = 3$), unless both parties' initial willingness is low, integrators choose information sharing strategies.

According to Figure 8, it can be seen that the evolution process of providers is the same as the integrator's behavior strategy evolution process. The evolution of the provider's behavior strategy is significantly affected by the initial

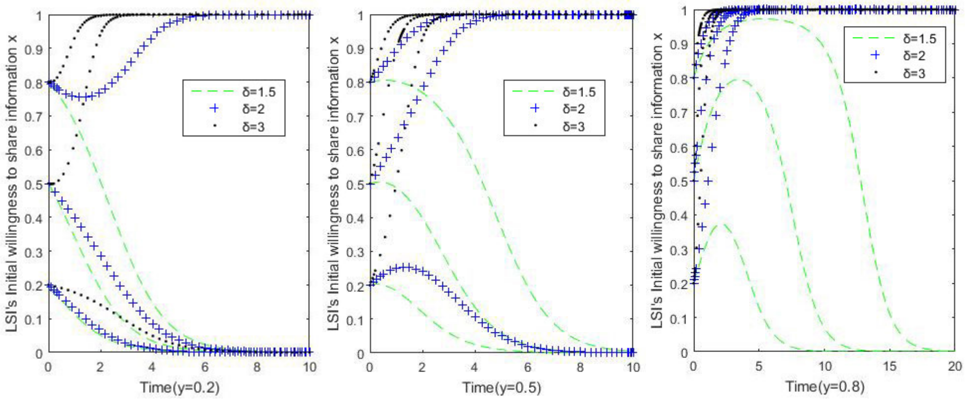

FIGURE 7. Effect of δ and initial willingness on integrator's evolutionary results.

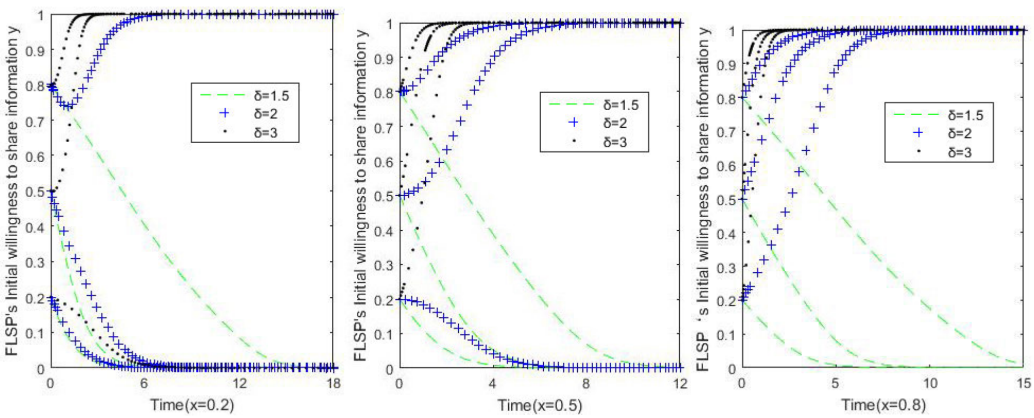

FIGURE 8. Effect of δ and initial willingness on the provider's evolutionary results.

willingness of both parties and the impact coefficient of investment in government infrastructure construction on the additional revenue. The evolution of provider behavior towards information sharing accelerates with the increase of their initial willingness. Compared with integrators, the evolution of provider behavior strategies is more affected by the initial willingness of both parties.

4. The impact of the initial willingness of both parties to choose information sharing and the force of government's incentives for enterprise information sharing α on the evolution of the behavior strategies of each gamer. α takes 4, 8, 16 respectively, and then the corresponding game evolution results are shown in Figure 9-10.

According to Figure 9, the integrator's behavior strategy is significantly affected by the initial willingness of both parties and the force of government's incentives for enterprise information sharing.

When the force of government's incentives for enterprise information sharing is low ($\alpha = 4$), the integrators will evolution in the direction of the information non-sharing. When the force of government's incentives for enterprise information sharing is medium ($\alpha = 8$), if the sum of the initial willingness of both parties is greater than or equal to 1, the integrators will evolution in the direction of information sharing, and if the sum of the initial willingness of both parties is less than 1, the integrators will evolution in the direction of information non-sharing. When the force of government's incentives for enterprise information sharing is high ($\alpha = 16$), all of the integrators will evolution in the direction of information sharing.

It can be seen from Figure 10 that the provider's behavior strategy is significantly affected by the force of government's incentives for enterprise information sharing behavior, and the evolution of its behavior strategy is the same as the situation of the integrator in Figure 9.

5. The impact of the initial willingness of both parties to choose information sharing and the information sharing risk coefficient θ on the evolution of the behavior strategies of each gamer. θ takes 0.2, 0.5, 0.8 respectively, then the corresponding game evolution results are shown in Figure 11-12.

It can be seen from Figure 11 and Figure 12 that the logistic company's behavior strategies are significantly affected by the information sharing risk coefficient, the speed of evolution of the behavioral strategy of the gamers is affected by the initial willingness of both parties to choose information

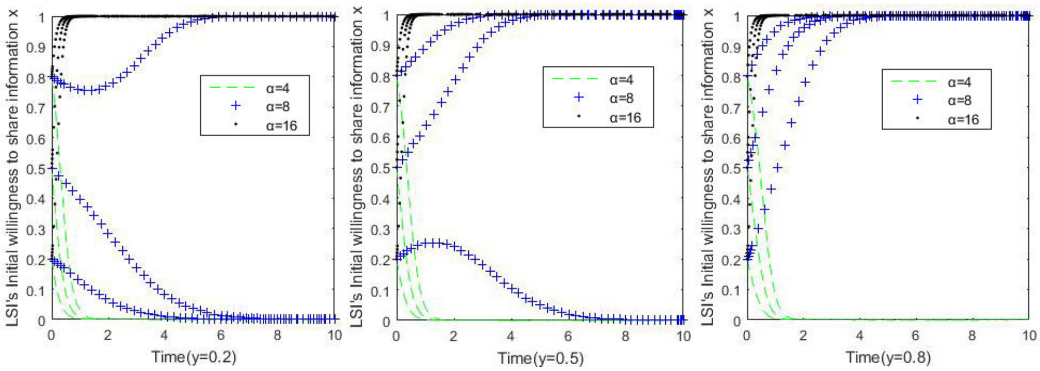

FIGURE 9. Effect of α and initial willingness on integrator's evolutionary results.

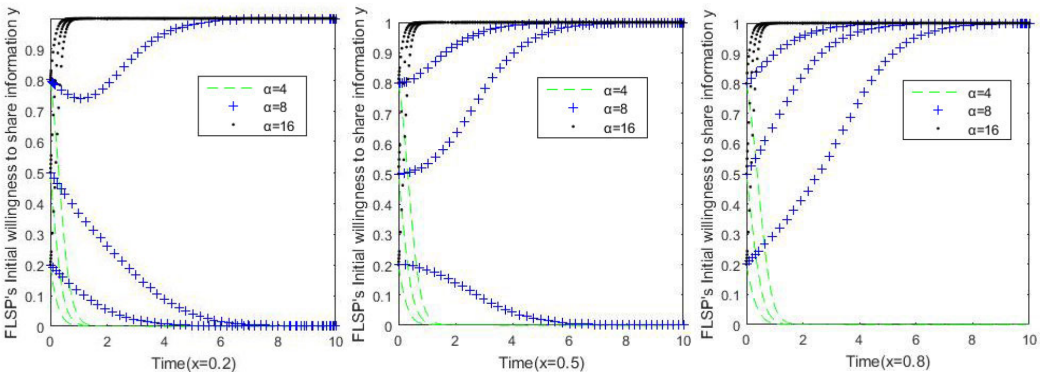

FIGURE 10. Effect of α and initial willingness on the provider's evolutionary results.

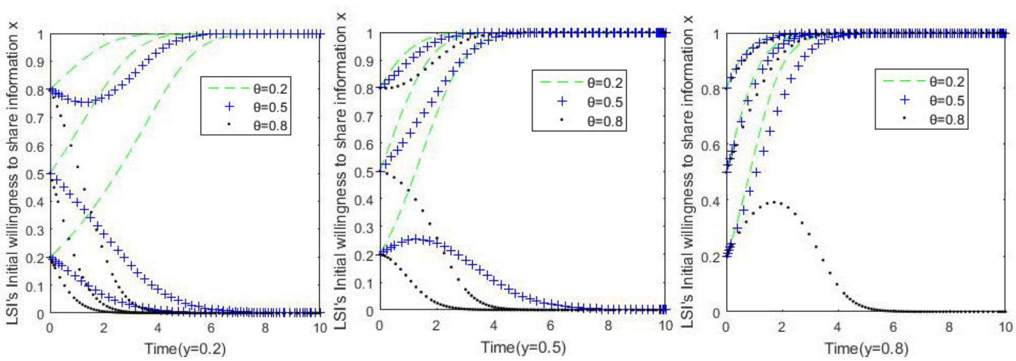

FIGURE 11. Effect of θ and initial willingness on integrator's evolutionary results.

sharing. When the information sharing risk coefficient is low ($\theta = 0.2$), the integrators and providers will evolution in the direction of information sharing. When the information sharing risk coefficient is medium ($\theta = 0.5$), if the sum of the initial willingness of both parties is greater than or equal to 1, both parties will evolution in the direction of information sharing, and if the sum of the initial willingness of both parties is less than 1, both parties will evolution in the direction of information non-sharing. When the information sharing risk coefficient is high ($\theta = 0.8$), if the sum of the initial willingness of both parties is greater than 1, both parties will evolution in the direction of information sharing, and if the sum of the initial willingness of both parties is less than or equal to 1, both parties will evolution in the direction of information non-sharing.

6. The impact of the initial willingness of both parties to choose information sharing and the speculative income coefficient K on the evolution of the behavior strategies of each gamer. K takes 0.5, 1, 2 respectively, then the corresponding game evolution results are shown in Figure 13-14.

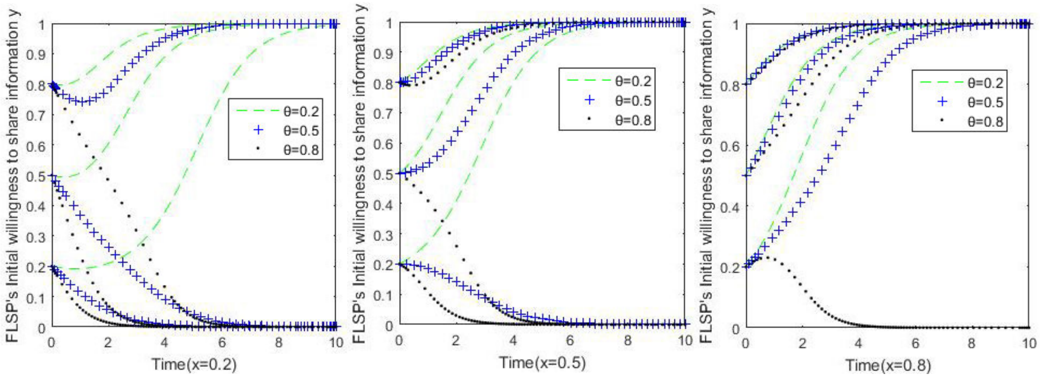

FIGURE 12. Effect of θ and initial willingness on the provider's evolutionary results.

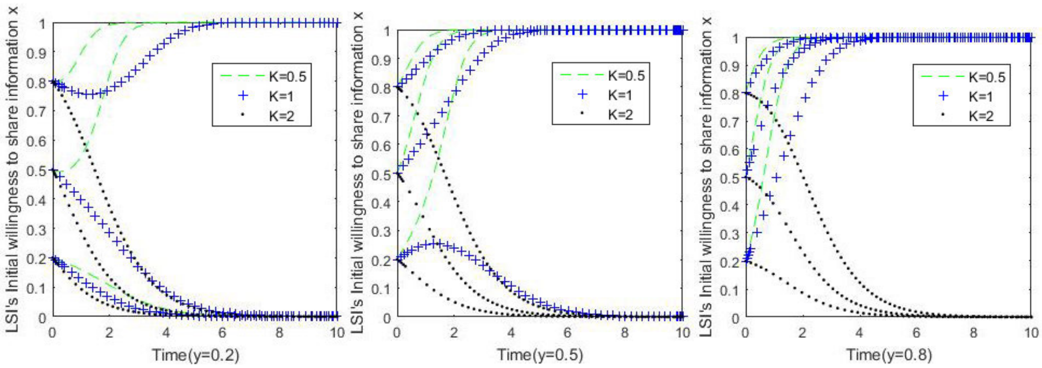

FIGURE 13. Effect of K and initial willingness on integrator's evolutionary results.

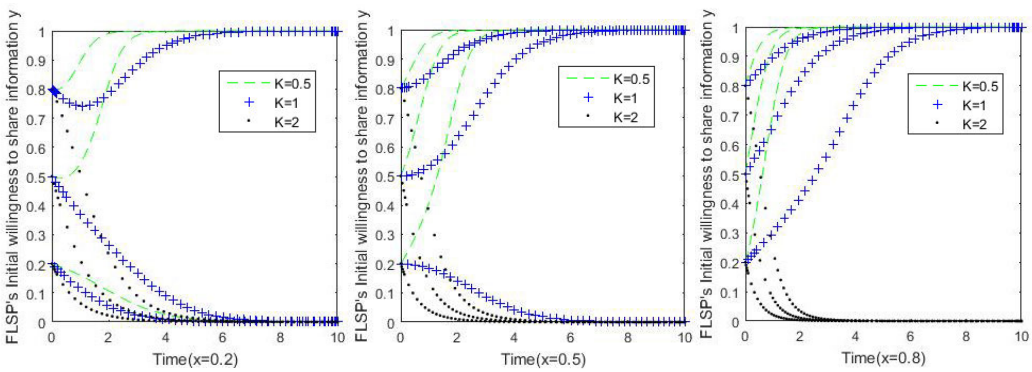

FIGURE 14. Effect of K and initial willingness on the provider's evolutionary results.

It can be seen from Figure 13 and Figure 14 that the logistic company's behavior strategies are significantly affected by the speculative income coefficient. When the speculative income coefficient is low ($K = 0.5$), both parties will evolution in the direction of information sharing, but if one of the two parties' initial willingness is low ($x = 0.2$ or $y = 0.2$), the other party will evolution in the direction of information non-sharing. When the speculative income coefficient is medium ($K = 1$), if the sum of the initial willingness of both parties is greater than or equal to 1, both parties will evolution in the direction of information sharing, and if the sum of the initial willingness of both parties is less than 1, both parties will evolution in the direction of information non-sharing. When the speculative income coefficient is high ($K = 2$), both parties will evolution in the direction of information non-sharing.

VI. CONCLUSION AND MANAGEMENT INSIGHTS

A. MAIN CONCLUSION

Taking into account the impact of the BRI, this paper analyzes the strategies of government incentives, government infrastructure construction, enterprise revenue distribution, information sharing costs, information sharing risks, and speculative income coefficients on logistics service supply chain information sharing strategies based on an evolutionary game model. The impact of the following five main conclusions:

1. Gamers' initial willingness to share information is proportional to additional benefits of information sharing. When the revenue distribution coefficient of information sharing is at a medium and high level, the probability of information sharing between gamers is inversely proportional. When the revenue distribution coefficient of information sharing is low, the strategy selection of information sharing between gamers depends on the initial willingness of both parties.

2. The choice of logistics enterprise information sharing strategy is significantly affected by the impact coefficient of investment in government infrastructure construction on additional revenue. When the impact coefficient of investment in government infrastructure construction on additional revenue is low, both parties choose the strategy of information non-sharing; when the impact coefficient of investment in government infrastructure construction on additional revenue is at a medium level, if one of the parties has a high initial willingness, then both parties will choose information sharing strategy, otherwise, both parties will choose information non-sharing; when the impact coefficient of investment in government infrastructure construction on additional revenue is high, both parties will choose information sharing strategy except for the initial willingness of both parties are all low.

3. The government's incentives for corporate information sharing behavior are directly proportional to the probability of logistics companies choosing information sharing. When the force of government's incentives for enterprise information sharing is medium or high, the integrator and the provider with the medium or high initial willingness will choose the information sharing strategy.

4. The information sharing risk coefficient is directly proportional to the probability of the logistics enterprise choosing information sharing. When the information sharing risk coefficient is low, both the integrator and the provider will choose the information sharing strategy. When the information sharing risk coefficient is medium or high, the choice of strategy depends on the initial willingness of both parties. If the initial willingness of one of the parties is high, the other party will have more possibility to choose information sharing.

5. When the speculative income coefficient is low, both the integrator and the provider will choose the information sharing strategy except the companies with low initial willingness. When the speculative income coefficient is medium, companies with higher initial willingness have a higher probability of choosing information sharing. When the speculative income coefficient is high, both the integrator and the provider will evolution in the direction of information non-sharing.

B. MANAGEMENT INSIGHTS

1. Integrators should play the core leading role of logistics service supply chain, guide the upstream and downstream enterprises of LSSC to strengthen information sharing, form economies of scale so as to obtain long-term benefits. For logistics enterprises, the main purpose of choosing business strategies is to obtain higher income, and the choice of information sharing strategies between integrators and providers largely depends on the additional income gained from information sharing and the risk of information sharing. But for LSSC, information sharing requires the joint participation and cooperation of many companies, and the overall benefit of LSSC needs to be achieved through long-term information sharing. Therefore, for integrators, they are at the core of LSSC, can connect upstream and downstream enterprises, and play an important role in the process of information sharing. First, integrators should take the initiative to share information and increase their initial willingness to share information, thereby increasing the probability of provider information sharing; Second, the integrator should agree on a reasonable revenue distribution method with the provider through contracts, agreements and so on, while ensuring the integrator's benefits while maximizing the provider's profit, thereby increasing the provider's willingness to share information. Third, the integrator should improve the information sharing platform functions and permissions, and only allow companies that share information to enter the platform to protect the interests of information sharing companies and reduce the speculative income coefficient.

2. Governments along the route should increase infrastructure construction and give appropriate subsidies to information sharing companies. First, the national conditions of the countries along the BRI vary; the economic level and technical capabilities of the countries vary greatly. The government should strengthen the construction of infrastructures such as 5G base stations and railway routes, and build an effective platform for efficient information sharing to improve the level of international logistics. Second, give enterprises appropriate subsidies, provide certain subsidies and rewards to integrators who actively build logistics information sharing platforms; improve platform information sharing mechanisms and management mechanisms, and provide certain subsidies and rewards to providers who actively undertake information sharing, and then increasing the probability of enterprise information sharing. Third, strengthen the information sharing enterprise's publicity and promotion, and provide technical support and fund subsidies to logistics companies that have invested a lot of manpower and material resources in actively building logistics information platforms and promoting LSSC information sharing. Set models and standards in the industry and promote the long-term development of LSSC information sharing.

ACKNOWLEDGMENTS

The authors would like to acknowledge the professionals who collaborated on this study. They would also like to thank all the reviewers who provided suggestions to improve this paper.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

REFERENCES

[1] C. Wang and F. Wang, "China can lead on climate change," *Science*, vol. 357, no. 6353, pp. 761–764, Aug. 2017.

[2] N. Rolland, "China's 'belt and road initiative': Underwhelming or game-changer?" *Washington Quart.*, vol. 40, no. 1, pp. 127–142, 2017.

[3] L. K. Cheng, "Three questions on China's 'belt road initiative,'" *China Econ. Rev*, vol. 40, pp. 309–313, Sep. 2016.

[4] L. Han, B. Han, X. Shi, B. Su, X. Lv, and X. Lei, "Energy efficiency convergence across countries in the context of China's belt and road initiative," *Appl. Energy*, vol. 213, pp. 112–122, Mar. 2018.

[5] Y.-J. Zhang and K.-B. Zhang, "The linkage of CO_2 emissions for China, EU, and USA: Evidence from the regional and sectoral analyses," *Environ. Sci. Pollut. Res.*, vol. 25, no. 20, pp. 20179–20192, Jul. 2018.

[6] Y. Huang, "Understanding China's belt & road initiative: Motivation, framework and assessment," *China Econ. Rev.*, vol. 40, pp. 314–321, Sep. 2016.

[7] K. Shi, B. Yu, C. Huang, J. Wu, and X. Sun, "Exploring spatiotemporal patterns of electric power consumption in countries along the belt and road," *Energy*, vol. 150, pp. 847–859, May 2018.

[8] F. Duan, Q. Ji, B.-Y. Liu, and Y. Fane, "Energy investment risk assessment for nations along China's belt & road Initiative," *J. Cleaner Prod.*, vol. 170, pp. 535–547, Jan. 2018.

[9] X. Liu, K. Zhang, B. Chen, J. Zhou, and L. Miao, "Analysis of logistics service supply chain for the one belt and one road initiative of China," *Transp. Res. Part E, Logistics Transp. Rev.*, vol. 117, pp. 23–39, Sep. 2018.

[10] H. K. Chan, J. Dai, X. Wang, and E. Lacka, "Logistics and supply chain innovation in the context of the belt and road initiative (BRI)," *Transp. Res. Part E, Logistics Transp. Rev.*, vol. 132, pp. 51–56, Dec. 2019.

[11] K. L. Choy, C. L. Li, S. C. So, H. Lau, S. K. Kwok, and D. Leung, "Managing uncertainty in logistics service supply chain," *Int. J. Risk Assessment Manage.*, vol. 7, no. 1, pp. 19–22, 2007.

[12] W. H. Liu, J. H. Ji, and D. Zhang, "Quality supervision and coordination off logistics capability cooperation in logistics service supply chain," in *Proc. 13th Int. Conf. Ind. Eng. Manage.*, vol. 5, 2006, pp. 1344–1350.

[13] L. Wei-Hua, X. Xue-Cai, R. Zheng-Xu, and P. Yan, "An emergency order allocation model based on multi-provider in two-echelon logistics service supply chain," *Supply Chain Manage., Int. J.*, vol. 16, no. 6, pp. 391–400, Sep. 2011.

[14] M. Ganesh, S. Raghunathan, and C. Rajendran, "The value of information sharing in a multi-product, multi-level supply chain: Impact of product substitution, demand correlation, and partial information sharing," *Decis. Support Syst.*, vol. 58, pp. 79–94, Feb. 2014.

[15] L. Li and H. Zhang, "Confidentiality and information sharing in supply chain coordination," *Manage. Sci.*, vol. 54, no. 8, pp. 1467–1481, Aug. 2008.

[16] H. L. Lee, K. C. So, and C. S. Tang, "The value of information sharing in a two-level supply chain," *Manage. Sci.*, vol. 46, no. 5, pp. 626–643, May 2000.

[17] A. Verma and S. Kaushal, "Deadline constraint heuristic-based genetic algorithm for workflow scheduling in cloud," *Int. J. Grid Utility Comput.*, vol. 5, no. 2, pp. 96–106, 2014.

[18] W. Liu, R. Wu, Z. Liang, and D. Zhu, "Decision model for the customer order decoupling point considering order insertion scheduling with capacity and time constraints in logistics service supply chain," *Appl. Math. Model.*, vol. 54, pp. 112–135, Feb. 2018, doi: 10.1016/j.apm.2017.09.027.

[19] W. Liu, X. Shen, and D. Xie, "Decision method for the optimal number of logistics service providers with service quality guarantee and revenue fairness," *Appl. Math. Model.*, vol. 48, pp. 53–69, Aug. 2017.

[20] G. Schmidt and W. E. Wilhelm, "Strategic, tactical and operational decisions in multi-national logistics networks: A review and discussion of modeling issues," *Int. J. Prod. Res.*, vol. 38, no. 7, pp. 501–523, 2000.

[21] G. Persson and H. Virum, "Growth strategies for logistics service providers: A case study," *Int. J. Logistics Manage.*, vol. 12, no. 1, pp. 53–64, Jan. 2001.

[22] S. Hertz and M. Alfredsson, "Strategic development of third party logistics providers," *Ind. Marketing Manage.*, vol. 32, no. 2, pp. 139–149, Feb. 2003.

[23] W. Liu, D. Xie, Y. Liu, and X. Liu, "Service capability procurement decision in logistics service supply chain: A research under demand updating and quality guarantee," *Int. J. Prod. Res.*, vol. 53, no. 2, pp. 488–510, Jan. 2015.

[24] J. Cai, X. Hu, P. R. Tadikamalla, and J. Shang, "Flexible contract design for VMI supply chain with service-sensitive demand: Revenue-sharing and supplier subsidy," *Eur. J. Oper. Res.*, vol. 261, no. 1, pp. 143–153, Aug. 2017.

[25] W.-H. Liu, D. Xie, and X.-C. Xu, "Quality supervision and coordination of logistic service supply chain under multi-period conditions," *Int. J. Prod. Econ.*, vol. 142, no. 2, pp. 353–361, Apr. 2013.

[26] J. Yao and L. Liu, "Optimization analysis of supply chain scheduling in mass customization," *Int. J. Prod. Econ.*, vol. 117, no. 1, pp. 197–211, Jan. 2009.

[27] T. Yu, "Supplier selection in constructing logistics service supply chain," *Syst. Eng.-Theory Pract*, vol. 23, no. 5, pp. 49–53, 2003.

[28] A. P. Cui and W. Liu, "Study on capability coordination in logistics service supply chain with options contract," *Chin. J. Manage. Sci.*, vol. 17, no. 2, pp. 59–65, 2009.

[29] W. Liu, C. Liu, and M. Ge, "An order allocation model for the two-echelon logistics service supply chain based on cumulative prospect theory," *J. Purchasing Supply Manage.*, vol. 19, no. 1, pp. 39–48, Mar. 2013.

[30] W. Liu, S. Wang, D. Zhu, D. Wang, and X. Shen, "Order allocation of logistics service supply chain with fairness concern and demand updating: Model analysis and empirical examination," *Ann. Oper. Res.*, vol. 268, nos. 1–2, pp. 177–213, Sep. 2018.

[31] W. Liu, Z. Liang, Z. Ye, and L. Liu, "The optimal decision of customer order decoupling point for order insertion scheduling in logistics service supply chain," *Int. J. Prod. Econ.*, vol. 175, pp. 50–60, May 2016.

[32] W. Liu, Q. Wang, Q. Mao, S. Wang, and D. Zhu, "A scheduling model of logistics service supply chain based on the mass customization service and uncertainty of FLSP's operation time," *Transp. Res. Part E, Logistics Transp. Rev.*, vol. 83, pp. 189–215, Nov. 2015.

[33] Y. Zhong, F. Guo, Z. Wang, and H. Tang, "Coordination analysis of revenue sharing in E-Commerce logistics service supply chain with cooperative distribution," *SAGE Open*, vol. 9, no. 3, Jul. 2019, Art. no. 215824401987053.

[34] W. Liu, Y. Yang, X. Li, H. Xu, and D. Xie, "A time scheduling model of logistics service supply chain with mass customized logistics service," *Discrete Dyn. Nature Soc.*, vol. 2012, pp. 1–18, 2012.

[35] F. M. Avalos, *The Two Sided Coin: An Examination of On-Line And Off-Line Communication in Social Justice Movements*. Claremont, CA, USA: Claremont Graduate Univ., 2009.

[36] M. Khan, M. Hussain, and H. M. Saber, "Information sharing in a sustainable supply chain," *Int. J. Prod. Econ.*, vol. 181, pp. 208–214, Nov. 2016.

[37] R. Dubey, N. Altay, A. Gunasekaran, C. Blome, T. Papadopoulos, and S. J. Childe, "Supply chain agility, adaptability and alignment: Empirical evidence from the Indian auto components industry," *Int. J. Oper. Prod. Manage.*, vol. 38, no. 1, pp. 129–148, Jan. 2018.

[38] D. C. Chatfield, J. G. Kim, T. P. Harrison, and J. C. Hayya, "The bullwhip effect—Impact of stochastic lead time, information quality, and information sharing: A simulation study," *Prod. Oper. Manage.*, vol. 13, no. 4, pp. 340–353, 2004.

[39] P. Fiala, "Information sharing in supply chains," *Omega*, vol. 33, no. 5, pp. 419–423, 2005.

[40] C. Chandra, J. Grabis, and A. Tumanyan, "Problem taxonomy: A step towards effective information sharing in supply chain management," *Int. J. Prod. Res.*, vol. 45, no. 11, pp. 2507–2544, 2007.

[41] A. Y. Ha, S. Tong, and H. Zhang, "Sharing demand information in competing supply chains with production diseconomies," *Math. Oper. Res.*, vol. 57, no. 3, pp. 566–581, 2011.

[42] A. Arya, B. Mittendorf, and D.-H. Yoon, "Revisiting the Make-or-Buy decision: Conveying information by outsourcing to rivals," *Accounting Rev.*, vol. 89, no. 1, pp. 61–78, Jan. 2014.

[43] H. Zhang, "Vertical information exchange in a supply chain with duopoly retailers," *Prod. Oper. Manage.*, vol. 11, no. 4, pp. 531–546, Jan. 2009.

[44] J. Alboszta and J. Mie, "Stability of evolutionarily stable strategies in discrete replicator dynamics with time delay," *J. Theor. Biol.*, vol. 231, no. 2, pp. 175–179, Nov. 2004.

[45] J. Maynard Smith, "The theory of games and the evolution of animal conflicts," *J. Theor. Biol.*, vol. 47, no. 1, pp. 209–221, Sep. 1974.

[46] J. M. Smith and G. R. Price, "The logic of animal conflict," *Nature*, vol. 246, no. 5427, pp. 15–18, 1973.
[47] J. W. Weibull. *Evolutionary Game Theory*. Cambridge, MA, USA: MIT Press, 1997, p. 8.
[48] L. Wang and G. Liu, "Research on information sharing mechanism of network organization based on evolutionary game," in *Proc. IOP Conf. Ser., Earth Environ. Sci.*, 2018, vol. 113, no. 1.
[49] J. Tan, G. Jiang, and Z. Wang, "Evolutionary game model of information sharing behavior in supply chain network with agent-based simulation," *Int. J. Intell. Inf. Technol.*, vol. 15, no. 2, pp. 54–68, Apr. 2019.
[50] S. Jiang, Z. Panpan, and X. Man, "Research on evolutionary game of information sharing with online health community," *J. Phys., Conf. Ser.*, vol. 1060, Jul. 2018, Art. no. 012084.
[51] Y. Tang, Z. Wang, Y. Zhang, and R. Fang, "Analysis on information sharing in forest product supply chain based on evolutionary game theory," *J. Européen des Systèmes Automatisés*, vol. 52, no. 6, pp. 625–630, Dec. 2019.
[52] M. A. Kaaouache and S. Bouamama, "Solving bin packing problem with a hybrid genetic algorithm for VM placement in cloud," *Procedia Comput. Sci.*, vol. 60, no. 1, pp. 1061–1069, 2015.
[53] G. Wang, X. Hu, X. Li, Y. Zhang, S. Feng, and A. Yang, "Multiobjective decisions for provider selection and order allocation considering the position of the CODP in a logistics service supply chain," *Comput. Ind. Eng.*, vol. 140, Feb. 2020, Art. no. 106216.
[54] Y. Xue and L. Ge, "Cost optimization control of logistics service supply chain based on cloud genetic algorithm," *Wireless Pers. Commun.*, vol. 102, no. 4, pp. 3171–3186, Oct. 2018.
[55] W. Gu, L. Wei, W. Zhang, and X. Yan, "Evolutionary game analysis of cooperation between natural resource- and energy-intensive companies in reverse logistics operations," *Int. J. Prod. Econ.*, vol. 218, pp. 159–169, Dec. 2019.
[56] D. Friedman, "Evolutionary games in economics," *Econometrica*, vol. 59, no. 3, pp. 637–666, 1991.

GUOHAO LI was born in Pingdu City, China, in 1975. He received the B.S. degree in mechanical and electronics engineering and the M.S. degree in management science and engineering from Jiangsu University, in 1998 and 2001, respectively, and the Ph.D. degree in technical economics and management from Hehai University, Nanjing, in 2008.

He has visited the University of Virginia (UVA) and the School of Management, Fudan University. From 2011 to 2012, he served as the Deputy Secretary of the Town Party Committee in Qidu Town, Wujiang City. From 2013 to 2014, he served as the Deputy District Governor of Jingkou District, Zhenjiang City. From 2015 to 2016, he was a Visiting Scholar at The Ohio State University (OSU). He is currently a Professor and the Deputy Dean of the School of Management, Jiangsu University.

QI ZHANG was born in Nantong, China, in 1995. She received the B.S. degree in industrial engineering from the Nanjing Institute of Technology, Nanjing, China, in 2018. She is currently the master's degree in industrial engineering with Jiangsu University.

She is currently presiding over a postgraduate innovation project in Jiangsu province. She once presided over a school-level research project and has completed it. Her research interests include logistics and supply chain management.

ZHENGYU BAI was born in Zibo, China, in 1995. He received the B.S. degree in industrial engineering from Qingdao University, Qingdao, China, in 2018. He is currently pursuing the master's degree in logistics engineering with Jiangsu University.

He once presided over a school-level research project and has completed it. He is currently participating in a research on the China's 13th Five-Year Plan. His research interests include logistics and supply chain management.

PERVAIZ SABEEH was born in a Islamabad, Pakistan, in 1991. He received the B.B.A. degree (Hons.) degree from COMSATS University Islamabad and the M.Sc. degree from Riphah International University. He is currently pursuing the Ph.D. degree in management sciences with Jiangsu University, China.

He served as a visiting lecturer at several universities from 2016 to 2018. His specialties are in the subjects of business and organizational psychology and management. During his tenure as a Ph.D. Scholar, he has published three international and several articles are in review with top journals in organizational psychology. He has presented his research at many international and national symposiums with good feedback and won the prize as the best research paper in the field of management at the SAISON International Conference in 2014. He worked as a Research Associate at COMSATS University Islamabad from 2014 to 2016. His research interests include organizational psychology, leadership, organizational justice, and change management.