Evolutionary game analysis of promoting the development of green logistics under government regulation

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Graphical abstract

Influence degree of different parameters on logistics greening.

Public summary

This paper constructs an evolutionary game model, discusses the green behavior of logistics enterprises from a dynamic perspective, and analyzes the evolutionary mechanism of logistics enterprises implementing green logistics.

Considering the evolutionary game model composed of government, enterprises and consumers, we analyze the evolutionary paths and results of green logistics implementation by enterprises under government regulation from a systematic perspective, which can better portray the interactions among the three parties.

Using ABM simulation method and Netlogo software, we quantitatively study the micro-mechanism of implementing green logistics in enterprises from the bottom-up perspective of micro interaction to macro emergence.

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Abstract: Due to the strong negative externalities of traditional logistics, the green logistics that developed from traditional logistics has the advantages of saving resources and protecting the environment. However, in the competitive market environment, enterprises will not implement green logistics based on their own revenue and competitiveness and, instead, will choose the best choice from the actions of a series of internal and external factors. To explore the effect of various factors on the implementation of green logistics by enterprises, this study constructs a tripartite evolutionary game model of the government, logistics enterprises, and users from the perspective of the participants in the process of logistics greening and analyzes the evolutionarily stable strategy of each participant under different situations. The Netlogo software is used to simulate and analyze the initial willingness of the participants, the intensity of government subsidies and penalties, and the probability that the enterprise’s speculative behavior is founded on the system’s evolutionary paths and results. The results demonstrate that the initial willingness to participate of the government, logistics enterprises, and users has different effects on the evolutionary results of the system. The government subsidy and penalty measures significantly impact the strategic choice of enterprises and users. Compared with users, enterprises are more sensitive to government subsidies, and compared with tax penalties, government subsidies have a greater impact on enterprises’ behavior choices. Moreover, the government should strengthen the publicity of green logistics and formulate judgment standards and an evaluation system for green enterprise logistics, and restrain the speculative behavior of enterprises.

Keywords: Green logistics; evolutionary game; government regulation

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1 Introduction

Statistics from the China Federation of Logistics and Purchasing in 2012 indicate that in the entire link from production to sales, only 5% of the time is spent on manufacturing and processing, and nearly 95% of the time is spent on logistics and transportation. However, this series of logistics and transportation links will inevitably cause negative externalities, such as the use of chemicals during storage, the emission of vehicle exhaust and noise pollution during transportation, and the misuse of packaging materials. This negatively impacts the ecological environment, wastes natural resources, and does not meet the strategic requirements of sustainable economic and social development.

Due to the many negative externalities in traditional logistics activities, green logistics has gradually entered the public eye. In the early days, the public did not pay much attention to green logistics. Due to the increasingly prominent environmental and resource problems in recent years, domestic and foreign scholars and business managers began to focus on green logistics. In addition, monographs on green logistics theory and methods have been published successively. Murphy points out that academic interest in logistics environmental issues appears to be growing, with growing interest in "greening" logistics.

Subsequently, different scholars and relevant organizations have defined green logistics according to their own understanding. Wu and Dunn believe that producing a product from scratch is inseparable from the role of green logistics: from the acquisition of raw materials to production and processing, packaging design, transportation, and circulation of products, to the final delivery to users. This is the positive logistics process, but the reverse processes such as waste recycling and disposal are also a part of green logistics. The Reverse Logistics Executive Committee believes that green logistics is a logistics process that minimizes its impact on the ecological environment. In the “Logistics Terminology” (GB/T18354-2001) promulgated in China in 2001, green logistics is defined as the process of refining the logistics environment in the logistics process, reducing the negative impact of logistics on the environment, and maximizing the use of logistics resources. While many Chinese scholars have adopted this definition, other scholars have explained the definition of green logistics from the perspective of its characteristics. For example, Chen believes that the green support of green logistics to the environment and products constitutes its double green characteristics. Feng believes that green logistics is an economic activity process that connects
the subject of green supply and demand and ensures the rapid flow of green goods or green services. Additionally, many scholars are putting forward suggestions to promote the development of green logistics from the perspective of policy. Pigou [15], the founder of welfare economics, believes that due to the difference between marginal private net output value and marginal social net output value, it is impractical for neoclassical economics to posit that the optimal allocation of resources is formed entirely by relying on the market mechanism to realize a Pareto optimization. Therefore, it is necessary to rely on government taxation or regulation to address the widespread externalities in economic activity. North Douglass [16] believes that "externalities exist when the individual costs caused by individual actions are not equal to the social costs and the individual benefits are not equal to the social benefits". Usually, the existence of externalities will lead to unreasonable resource allocation (or low efficiency), that is, "market failure". Gong [17] summarized the practical exploration and typical experience of the development of green logistics at home and abroad, combined with the new needs of China's economic and social green development, evaluated the characteristics and shortcomings of the existing research, and proposed that it is of great importance to build a theoretical framework system of logistics system with green development as the basic content. Aibin Li's [17] research demonstrates that the policy system can directly affect the willingness to implement green logistics. Liang [18] analyzed the risks of negative externalities of enterprises from two aspects of time and space and pointed out that the government should formulate incentive policies from three specific levels—industry, taxation, and procurement—to promote enterprises to bear corresponding responsibilities and achieve sustainable development.

In addition, some scholars have made suggestions on modern green logistics management methods and concepts. Agyabeng Mensah [19] takes a positive attitude towards implementing green logistics management and believes that it has a significant positive impact on the environment. Chen [20] believes that modern green logistics management is a new type of logistics management that meets the development requirements of the times and the interests of human survival and development. He discusses the theoretical basis of sustainable development, ecological economics and ecological ethics of modern green logistics management and argues that the non-green factors that may affect the environment include the six elements that constitute modern logistics. Finally, researchers have proposed strategies for modern logistics management and its development. These include specific suggestions from the perspective of the construction of a logistics management mode and system, such as green logistics development planning, shaping green logistics brands, and choosing green transportation strategies [19-22].

In recent years, some scholars have used game theory to study the development of green logistics and achieved some important research results [23-25]. However, there are still some deficiencies in the existing research. First, most of the existing literature is based on the fully rationality of participants, discusses the green behavior of logistics enterprises from a static point of view, and lacks the analysis of the evolutionary mechanism of logistics enterprises implementing green logistics, while evolutionary game can effectively solve the shortcomings of the former. Second, users are not included in the game behavior. In China, with the development of economy, the public’s sense of social responsibility is increasing. After understanding the positive impact of green logistics on the social environment, users will be more inclined to support green logistics. However, due to obstacles such as information asymmetry and opacity in the logistics market, enterprises might have to speculate without government regulation and label traditional logistics as green logistics to deceive users. Consequently, to promote the process of logistics greening, this paper constructs a tripartite game model of government, logistics enterprises, and users using evolutionary game theory, discusses the strategic choice under different circumstances, and simulates the influence of various parameters on the evolutionary paths and results of the system through a numerical simulation.

2 Methods

2.1 Model Assumptions and construction

The implementation of green logistics requires the cooperation of governments, logistics enterprises and users. Based on evolutionary game theory, this paper takes the participants of enterprise logistics greening as the research center, and constructs an evolutionary game model that includes three types of subjects: government, logistics enterprise and user; they are bounded rational participants with the ability to learn and seek the best decision to pursue their own maximized economic utility. The assumptions about the model are as follows:

Assumption 1: In this game model, the governments have two strategies—to regulate or not to regulate; logistics enterprises have two strategies—to implement green logistics or not to implement green logistics; and users have two strategies—to purchase green logistics or to purchase traditional logistics. Since all three participants are bounded rational participants, they cannot make optimal decisions in the initial stage of the game. During the entire game process, the participants will dynamically adjust their strategies through learning and imitation until they reach an evolutionarily stable strategy.

Assumption 2: Drawing on Xu Jianzhong’s [16] research, the government’s regulatory measures include supervision, collection of environmental protection taxes, and subsidies. When the government chooses to regulate, it needs to invest cost $c$ for environmental protection publicity, environmental monitoring, and corporate supervision. At the same time, it will provide subsidy $B_1$ to enterprises that implement green logistics and subsidy $B_2$ to users that purchase green logistics; it will also impose an environmental protection tax $A_1$ on enterprises that do not implement green logistics. When the government chooses not to regulate, if the enterprise also does not implement green logistics at this time, this will negatively impact resources and the environment, cause a decline in the credibility of the government, and create government’s reputation loss set as $G$. DOI: 10.52396/JUSTC-2022-0067 JUSTC, 2022, 52(9):
Assumption 3: Implementing green logistics can improve the environment and resources and save the government $E$ in environmental governance costs. When the logistics enterprise chooses to implement green logistics, the general revenues are $T_1$, and the additional costs $c$ will be invested in technology research and process management of green logistics. In this case, since the price of green logistics is higher, the enterprise will also increase its revenues by $t$. When the logistics enterprise chooses not to implement green logistics, the general revenues are $T_2$. At this time, in the absence of government regulation, enterprises can take measures to raise prices to deceive users by labelling traditional logistics as green logistics, which can also obtain additional revenues of $r$. However, once the enterprise’s speculative behavior is recognized by users, the enterprise will lose $v$ in market revenue, where the probability that the enterprise’s speculative behavior is recognized by users is $\theta$ and $T_2 > T_1$.

Assumption 4: Let the general revenues of users purchasing traditional logistics be $R_t$ and $R_t > R_e$. When the consumer chooses to purchase green logistics, the general revenues are $R_e$. In this case, if the enterprise implements green logistics, users will gain additional revenues of $r$, which mainly refers to the improvement of service quality; if the enterprise adopts speculative behavior, users will lose the revenues of $s$.

The variables are summarized in Table 1 below.

### 2.2 Construction of evolutionary game model

Let $x$ denotes the proportion of government groups that choose to regulate and let $1 - x$ denotes the proportion of government groups that choose not to regulate. Suppose that $y$ denotes the proportion of logistics enterprise groups that choose to implement green logistics, and $1 - y$ denotes the proportion of logistics enterprise groups that choose not to implement green logistics. Let $z$ denotes the proportion of user groups that choose to purchase green logistics, and $1 - z$ denotes the proportion of user groups that choose to purchase traditional logistics, and $x, y, z \in [0, 1]$ are functions of time $t$.

According to the above four assumptions and parameter settings, the three-party game payoff matrix is illustrated in Table 2.

### 3 Tripartite Evolutionary Model Analysis

#### 3.1 Government Game Equilibrium Analysis

According to Table 2, the expected payoffs of the government that chooses to regulate is $U_{11}$, and the expected payoffs of choosing not to regulate is $U_{12}$, and the specific calculation is as follows:

$$U_{11} = x y z (E - K - B_1 - B_2) + y (1 - z) [E - K - B_1] + (1 - y) [z - K]$$

$$U_{12} = x y z E + y (1 - z) E + (1 - y) [z - K] + (1 - y) (1 - z) [-G]$$

The average payoff is $U_e$:

$$U_e = x U_{11} + (1 - x) U_{12}$$

According to evolutionary game theory [21], the replicator dynamics equation that governments choose to regulate is:

$$\frac{dx}{dt} = x (U_{11} - U_e) =
\begin{cases}
x(1 - x) \left[ (E - K - B_1 - B_2) y - B_3 y z - A + G - K \right] & \text{if } y = y_m
\end{cases}$$

(1) When $y = y_m$ the replicator dynamics equation is $F(x) = 0$. At this time, any $x$ point in the range of $[0, 1]$ is an equilibrium point of the replicator dynamics equation.

### Table 1. Variable description

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>General revenues when users purchase traditional logistics</td>
</tr>
<tr>
<td>$T_1$</td>
<td>General revenues when logistics enterprises choose not to implement green logistics</td>
</tr>
<tr>
<td>$B_1$</td>
<td>Government subsidies for enterprises that implement green logistics</td>
</tr>
<tr>
<td>$c$</td>
<td>The cost of implementing green logistics in enterprises</td>
</tr>
<tr>
<td>$v$</td>
<td>Market loss after enterprise’s speculation is found</td>
</tr>
<tr>
<td>$t$</td>
<td>Additional revenues for enterprises to implement green logistics</td>
</tr>
<tr>
<td>$E$</td>
<td>Reduction of environmental management costs for the government by implementing green logistics in enterprises</td>
</tr>
<tr>
<td>$K$</td>
<td>Government regulatory costs</td>
</tr>
<tr>
<td>$R_2$</td>
<td>General revenues when users purchase green logistics</td>
</tr>
<tr>
<td>$T_2$</td>
<td>General revenues when logistics enterprises choose to implement green logistics</td>
</tr>
<tr>
<td>$B_2$</td>
<td>Government subsidies for users that purchase green logistics</td>
</tr>
<tr>
<td>$\theta$</td>
<td>The probability that the enterprise’s speculation is found</td>
</tr>
<tr>
<td>$r$</td>
<td>Additional revenues for users to buy truly green logistics</td>
</tr>
<tr>
<td>$A$</td>
<td>Environmental protection tax for enterprises not implementing green logistics</td>
</tr>
<tr>
<td>$G$</td>
<td>Reputation loss caused when enterprises do not implement green logistics, and the government does not regulate</td>
</tr>
<tr>
<td>$s$</td>
<td>Loss of users when enterprises adopt speculative behaviors</td>
</tr>
</tbody>
</table>

### Table 2. Payment matrix of a governments, logistics enterprises and users

<table>
<thead>
<tr>
<th>Government</th>
<th>Logistics enterprise</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulate ($x$)</td>
<td>Implement green logistics $(y)$</td>
<td>$-K + A T_1 - A R_1$</td>
</tr>
<tr>
<td></td>
<td>Do not implement green logistics $(1 - y)$</td>
<td>$E - K - B_1 - B_2 T_2 + t - c + B_1 R_2 + r + B_2$</td>
</tr>
<tr>
<td>Do not regulate $(1 - x)$</td>
<td>Implement green logistics $(y)$</td>
<td>$-K + A T_1 - A R_1$</td>
</tr>
<tr>
<td></td>
<td>Do not implement green logistics $(1 - y)$</td>
<td>$E - K - B_1 - B_2 T_2 + t - c + B_1 R_2 + r + B_2$</td>
</tr>
</tbody>
</table>

DOI: 10.52396/JUSTC-2022-0067

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evolutionarily stable point, and the governments’ strategic choice does not change with time.

(2) When \( y \neq y_0 \), let \( F(x) = 0 \), the two stable points of the governments are \( x = 0 \) and \( x = 1 \). Derive \( F(x) \) to get
\[
\frac{dF(x)}{dx} = (1 - 2x)[-(B_1 + A + G)y - B_1z + A + G - K] \quad (5)
\]
If \( y > y_0 \), when \( x = 0 \), \( \frac{dF(x)}{dx} < 0 \); when \( x = 1 \), \( \frac{dF(x)}{dx} > 0 \), therefore, the evolutionarily stable point of the governments is \( x = 0 \). Similarly, when \( y < y_0 \), the evolutionarily stable point of the governments is \( x = 1 \).

According to formula (5), when the government’s supervision cost \( K \) decreases, \( y_0 \) increases, then the government is more inclined to choose to regulate. The greater the \( z \), the greater the willingness of users to purchase green logistics, and the more the government is inclined to choose not to regulate. This demonstrates that if most users have a strong sense of social responsibility and environmental protection awareness, and are willing to buy green logistics at a higher price than traditional logistics, then enterprises will implement green logistics to occupy the market share when they see the market demand for green logistics, and in this case, it is feasible that the government does not regulate.

### 3.2 Enterprise Game Equilibrium Analysis

The expected payoff of the logistics enterprise that chooses to implement green logistics is \( U_{it} \) and the expected payoff of choosing not to implement green logistics is \( U_{it}^{*} \), and the specific calculation is as follows:

\[
U_{it} = xz[T_1 + t - c + B_1] + x(1 - z)[T_2 - c + B_1] + (1 - x)z[T_1 + t - G] + (1 - x)(1 - z)[T_2 - c] \quad (6)
\]
\[
U_{it}^{*} = xz[T_1 - A] + x(1 - z)[T_1 - A] + (1 - x)z[T_1 + t - G] + (1 - x)(1 - z)t \quad (7)
\]

The average payoff is \( \overline{U}_{i} \):
\[
\overline{U}_{i} = yU_{it} + (1 - y)U_{it}^{*} \quad (8)
\]

The replicator dynamics equation that enterprises choose to implement green logistics is:
\[
F(y) = \frac{dy}{dt} = y\left(U_{it} - \overline{U}_{i}\right) = y(1 - y) \left[(B_1 + A)x + (1 - x)zG + tG + T_2 - T_1 - c\right] \quad (9)
\]

Let \( z_0 = T_1 + c - (B_1 + A) \frac{T_2 - T_1 - c}{(1 - x)G + t} \).

(1) When \( z = z_0 \), the replicator dynamics equation \( F(y) = 0 \), at this time, any \( y \) point in the range of \([0, 1]\) is an evolutionarily stable point, and the enterprises’ strategic choice does not change with time.

(2) When \( z \neq z_0 \), let \( F(y) = 0 \), the two stable points of the enterprise are \( y = 0 \) and \( y = 1 \). Derive \( F(y) \) to get
\[
\frac{d(F(y))}{dy} = (1 - 2y)[(B_1 + A)x + (1 - x)zG + tG + T_2 - T_1 - c] \quad (10)
\]

If \( z > z_0 \), when \( y = 0 \), \( \frac{d(F(y))}{dy} > 0 \); when \( y = 1 \), \( \frac{d(F(y))}{dy} < 0 \), therefore, the evolutionarily stable point of the enterprises is \( y = 1 \). Similarly, when \( z < z_0 \), the evolutionarily stable point of the enterprises is \( y = 0 \).

Through the analysis of the replicator dynamics equation of the enterprise, it can be found that whether the enterprise implements green logistics is mainly related to the cost of investment \( c \), the government subsidies \( B_1 \) that can be obtained, the environmental protection tax \( A \) that must be paid for not implementing green logistics, and the probability of being detected as a speculative behavior. When \( c \) and \( z_0 \) increase, the willingness of enterprises to choose to implement green logistics is lower. When \( \theta, B_1, \) and \( A \) increase, \( z_0 \) decreases, then enterprises are more inclined to choose to implement green logistics. From the analysis, the larger \( x \) is, the greater the willingness of the government to regulate, the more enterprises are inclined to choose to implement green logistics. This demonstrates that the government’s active regulatory behavior can effectively motivate enterprises to implement green logistics, but it does not mean that as long as the government regulates, enterprises will definitely implement green logistics as the strategic choices of enterprises are mainly related to the intensity of government regulatory behaviors. That is to say, when enterprises implement green logistics, they can obtain higher government subsidies, but when they have to pay high environmental protection taxes, enterprises will face greater external pressure, and the willingness to implement green logistics will be stronger. Therefore, the government should strengthen the supervision and management of the behavior of logistics enterprises and formulate and improve the strict subsidies and penalties mechanism to enhance the motivation of enterprises to implement green logistics.

### 3.3 User Game Equilibrium Analysis

The expected payoff for users that choose to purchase green logistics is \( U_{it} \) and the expected payoffs of choosing to purchase traditional logistics is \( U_{it}^{*} \), and the specific calculation is as follows:

\[
U_{ix} = xy[R_2 + r + B_2] + (1 - x)y[R_2 + r] + (1 - x)(1 - y)[R_2 - s] \quad (11)
\]
\[
U_{it}^{*} = xyR_1 + x(1 - y)R_1 + (1 - x)(1 - y)R_1 \quad (12)
\]

The average payoff is \( \overline{U}_{i} \):
\[
\overline{U}_{i} = yU_{ix} + (1 - y)U_{ix}^{*} \quad (13)
\]

The replicator dynamics equation that users choose to purchase green logistics is:
\[
F(z) = \frac{dz}{dt} = z\left(U_{ix} - \overline{U}_{i}\right) = z(1 - z) \left[(R_2 + r)y + B_2xy + (1 - x)(1 - y)(R_2 - s) - R_1\right] \quad (14)
\]

Let \( x_0 = \frac{R_2 - s - R_1 + (r + s)y}{(R_2 - s)(1 - y) - B_2y} \).

(1) When \( x \neq x_0 \), the replicator dynamics equation \( F(z) = 0 \); at this time, any \( z \) point in the range of \([0, 1]\) is an
evolutionarily stable point, and the users’ strategic choice does not change with time.

(2) If \( x > x_0 \), let \( F(z) = 0 \), the two stable points of the users are \( z = 0 \) and \( z = 1 \). Derive \( F(z) \) to get

\[
\frac{d(F(z))}{dz} = (1-2z)\left[(R_r + r)y + B_2xy + (1-x)(1-y)(R_r - s) - R_r\right]
\]

(15)

If \( x > x_0 \), when \( z = 0, \frac{d(F(z))}{dz} < 0 \); when \( z = 1, \frac{d(F(z))}{dz} > 0 \), therefore, the evolutionarily stable point of the users is \( z = 0 \). Similarly, when \( x < x_0 \), the evolutionarily stable point of the users is \( z = 1 \).

Through the analysis of the replicator dynamics equation of users, the main factors affecting users’ strategy choices are the government’s subsidies \( B_i \) for users who buy green logistics and the additional revenues \( r \) for users to purchase green logistics. When \( B_i \) and \( r \) increase, users’ willingness to buy green logistics will increase. Generally speaking, the market price of green logistics is higher than traditional logistics. When users choose logistics products, they will not only consider the social benefits of products but also be affected by the price of products. In the absence of government regulation, even if users have a strong sense of social responsibility and green preference, they will worry that they will pay the price of green logistics but not be able to consume the real green logistics. However, when the government chooses to regulate whether the logistics purchased by users are green or not can not only be guaranteed, but also, the government subsidies can exempt users from economic pressure and stimulate users’ enthusiasm for purchasing green logistics. At the same time, the purchase of green logistics can create additional effects, such as improving service quality and effectively encouraging users to choose green logistics, which requires enterprises to make corresponding facilities in the green logistics market and enhance users’ good consumption experience.

\[
J = \begin{bmatrix}
1 - 2x & -(B_1 + A + G)y & x(1-x)(-B_1 - A - G - B_r z) \\
-B_2yz + A + G - K & y(1-y)(B_1 + A - z\theta y + tz) & y(1-y)(1-x)[(1-x)\theta y + tx] \\
R_r + r + B_2x + (x-1)(R_r - s) & z(1-z)(B_2y + (y-1)(R_r - s)) & z(1-z)
\end{bmatrix}
\]

(17)

According to Selten’s research conclusion, in an asymmetric game, if the condition of information asymmetry holds, the evolutionarily stable strategy is pure strategy. Therefore, it is only necessary to discuss the local stability of the eight pure-strategy equilibrium points \( E_i = (0,0,0), E_l = (0,0,1), E_r = (0,1,0), E_1 = (0,1,1), E_2 = (1,0,0), E_3 = (1,0,1), E_4 = (1,1,0), E_5 = (1,1,1) \) that satisfy the equation set

\[
\begin{align*}
F(x) &= 0 \\
F(y) &= 0 \\
F(z) &= 0
\end{align*}
\]

According to Lyapunov’s first law, if the eigenvalues of the Jacobian matrix of each equilibrium point are all negative, the equilibrium point is the evolutionarily stable strategy of the game system. Let the Jacobian matrix corresponding to point \( E_i = (0,0,0) \) be \( J_i \), then \( J_i = \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \). The eigenvalues of the Jacobian matrix \( J_i \) can be obtained as \( \lambda_1 = A - K, \lambda_2 = -c, \) and \( \lambda_3 = R - r - s \). By analogy, the eigenvalues of the Jacobian matrix corresponding to the other seven equilibrium points can be obtained as illustrated in Table 3.

Observe the eigenvalues of each equilibrium point in Table 3 and analyze the stability of the system equilibrium point from the following five situations:

(1) When \( T_2 - T_1 - c > 0 \), that is, when there is no government regulation, the revenues obtained by enterprises after implementing green logistics are greater than the expenditures.

(a) When \( R_r + r + R_r > 0 \), that is, when the benefits of users buying green logistics are greater than those of buying traditional logistics, the system will gradually stabilize at point \( E_i = (0,1,1) \). This situation is the ideal state we hope to see; even if the government does not regulate, the total revenue of enterprises implementing green logistics is greater than those
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Table 3. Eigenvalues of each equilibrium point

<table>
<thead>
<tr>
<th>Equilibrium</th>
<th>Eigenvalues of $t_1$</th>
<th>Eigenvalues of $t_2$</th>
<th>Eigenvalues of $t_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1 = (0,0,0)$</td>
<td>$A + G - K$</td>
<td>$T_2 - T_1 - c$</td>
<td>$R_2 - R_1 - s$</td>
</tr>
<tr>
<td>$E_2 = (0,0,1)$</td>
<td>$A + G - K$</td>
<td>$\theta v + T_2 - T_1 - c$</td>
<td>$-R_2 + R_1 + s$</td>
</tr>
<tr>
<td>$E_3 = (0,1,0)$</td>
<td>$-B_1 - K$</td>
<td>$-T_2 + T_1 + c$</td>
<td>$R_2 + r - R_1$</td>
</tr>
<tr>
<td>$E_4 = (0,1,1)$</td>
<td>$-B_1 - K - B_2$</td>
<td>$-\theta v - T_2 + T_1 + c$</td>
<td>$-R_2 - r + R_1$</td>
</tr>
<tr>
<td>$E_5 = (1,0,0)$</td>
<td>$-A - G + K$</td>
<td>$B_1 + A - T_2 - T_1 - c$</td>
<td>$-R_1$</td>
</tr>
<tr>
<td>$E_6 = (1,0,1)$</td>
<td>$-A - G + K$</td>
<td>$B_1 + A + t + T_2 - T_1 - c$</td>
<td>$R$</td>
</tr>
<tr>
<td>$E_7 = (1,1,0)$</td>
<td>$B_1 + K$</td>
<td>$-B_1 + A - T_2 + T_1 + c$</td>
<td>$R_2 + r + B_2 - R_1$</td>
</tr>
<tr>
<td>$E_8 = (1,1,1)$</td>
<td>$B_1 + K + B_2$</td>
<td>$-B_1 - A - t + T_2 + T_1 + c$</td>
<td>$-R_2 - r - B_2 + R_1$</td>
</tr>
</tbody>
</table>

not implementing green logistics, and users’ revenues from purchasing green logistics are greater than that of purchasing traditional logistics. After comparing the revenues under the two options, enterprises will tend to implement green logistics, and users will tend to purchase green logistics.

(b) When $R_1 + r - R_1 < 0$, that is to say, when the enterprise implements green logistics, the revenues of users purchasing green logistics are less than that of purchasing traditional logistics, then the evolutionarily stable point of the system is $E_1 = (0,1,0)$. In this case, the motivation of enterprises to participate in the implementation of green logistics comes from the revenues obtained from investment and does not depend on the government regulation.

(2) When $T_2 - T_1 - c > 0$, $B_1 + A + T_2 - T_1 - c > 0$, $\theta v + T_2 - T_1 - c > 0$, that is, in the absence of government regulations, the revenues obtained by enterprises after implementing green logistics are less than the expenditure, and the revenues are higher when taking speculative behavior, but in the case of government regulation, it is higher when enterprises implement green logistics.

(a) When $R_2 - R_1 - s < 0$, that is to say, when the enterprise has speculative behavior, the revenues of users purchasing green logistics are greater than those of traditional logistics, and the evolutionarily stable point of system is $E_1 = (0,1,1)$. In this case, even if the enterprises may be speculative, users will tend to purchase green logistics based on their own revenues. Since the sum of the revenues and government subsidies received by enterprises for implementing green logistics is greater than the expenditure, governments and users will tend to implement green logistics greater than the expenses, government regulation can effectively motivate enterprises to implement green logistics in the initial stage of the game.

(b) When $R_2 - R_1 - s > 0$, that is, users get more revenues from purchasing green logistics than traditional logistics, but the result is opposite when enterprises adopt speculative behaviors. If $A + G - K < 0$, that is, when the revenues from government regulation are less than the credit loss caused by non-regulation, the evolutionarily stable point of the system will be located between $E_1 = (0,0,0)$ and $E_1 = (0,1,1)$; otherwise, the system will gradually stabilize at point $E_1 = (0,1,1)$. This situation is similar to the previous one; the government is willing to participate in regulation at the initial stage to guide enterprises to participate in the implementation of logistics greening.

(c) When $R_1 + r - R_1 < 0$, that is, when there is a speculative behavior in the enterprise, the revenues obtained by users from purchasing green logistics are less than that of traditional logistics. If $A + G - K < 0$, the evolutionarily stable point of the system will be located between $E_1 = (0,0,0)$ and $E_1 = (0,1,0)$; otherwise, the system will gradually stabilize at point $E_1 = (0,1,0)$. Since the sum of the revenues and government subsidies received by enterprises from implementing green logistics is greater than the expenditure, enterprises are more inclined to choose to implement green logistics. However, for users, if there is a speculative behavior of the enterprise, then they pay the price of green logistics but do not get the real green logistics service, which will damage their own income. Therefore, users are reluctant to take this risk and will be more inclined to purchase traditional logistics.

(3) When $B_1 + A + T_2 - T_1 - c > 0$, $\theta v + T_2 - T_1 - c < 0$, that is to say, the sum of the revenues and government regulations obtained by enterprises from implementing green logistics is greater than the expenditure, and the revenues of enterprises’ speculative behavior are greater than the total revenues of implementing green logistics.

(a) When $R_2 - R_1 - s > 0$, if $A + G - K < 0$, then the evolutionarily stable point of system is $E_1 = (0,0,1)$. That is to say, when the benefits of government regulation are less than the loss of regulation caused by non-regulation, the government is more inclined not to regulate. If the government’s choice is not to regulate, enterprises will choose speculative behaviors, but even if enterprises adopt speculative behaviors, users’ revenues from purchasing green logistics are greater than traditional logistics, so users’ best choice is to purchase green logistics.

(b) When $R_2 - R_1 - s < 0$, if $A + G - K < 0$, then the evolutionarily stable point of system is $E_1 = (0,0,0)$. In this case, based on the consideration of their own revenues, the government will tend not to regulate, enterprises will tend not to implement green logistics, and users will tend to purchase traditional logistics.

(4) When $B_1 + A + T_2 - T_1 - c < 0$, $\theta v + T_2 - T_1 - c > 0$, that is, the revenues of not implementing green logistics are higher in the case of government regulation, and the revenues of implementing green logistics are less than the absence of government regulations.

(a) When $R_2 - R_1 - s > 0$, the evolutionarily stable point of the system is located between $E_1 = (0,1,1)$ and $E_1 = (1,0,0)$. At this time, since users have greater benefits from purchasing green logistics, the active implementation of green logistics by enterprises can effectively motivate users to purchase...
green logistics.

(b) When \( R_2 + r - R_1 > 0, R_2 - R_1 - s < 0 \), if \( A + G - K < 0 \), the evolutionarily stable point of the system is located between \( E_1 = (0,0,0) \) and \( E_1 = (0,1,1) \); otherwise, the evolutionarily stable point of the system is located between \( E_2 = (1,0,0) \) and \( E_1 = (1,0,0) \).

(c) When \( R_2 + r - R_1 < 0 \), if \( A + G - K < 0 \), the evolutionarily stable point of the system is \( E_1 = (0,0,0) \); otherwise, the evolutionarily stable point of the system is \( E_1 = (1,0,0) \). In this case, even if the government chooses to regulate, enterprises can obtain subsidies for implementing green logistics, but the final revenues are still less than the expenditures, so enterprises tend not to implement green logistics. Similarly, users are more inclined to purchase traditional logistics.

(5) When \( B_1 + A + T_2 - T_1 - c < 0 \), that is, the revenues of not implementing green logistics are higher in the case of government regulation, and the revenues of adopting speculative behavior are higher in the absence of government regulation,

(a) When \( R_2 - R_1 - s > 0 \), if \( A + G - K < 0 \), the evolutionarily stable point of the system is \( E_1 = (0,0,1) \); otherwise, the evolutionarily stable point of the system is \( E_1 = (1,0,0) \). In the case that the governments choose regulation, as the subsidies and penalties are relatively light, enterprises tend not to implement green logistics on the premise of only considering the revenues, while users choose to buy green logistics is a better choice. However, enterprises will adopt speculative behaviors quicker when the government chooses not to regulate. Users will also choose to purchase traditional logistics after knowing the choice of enterprises. In this case, the government main regulatory strategy should be to increase tax penalties or subsidies and reduce the speculative behavior of enterprises.

(b) When \( R_1 - R_1 - s < 0 \), the government choose to regulate depends on the need to meet \( A + G - K > 0 \); that is, when the revenues obtained by government regulation are greater than the reputation loss caused by non-regulation, point \( E_2 = (1,0,0) \) is the evolutionarily stable point of the system; otherwise, the evolutionarily stable point of the system is \( E_1 = (0,0,0) \). In this case, after measuring their own revenues, enterprises and users will choose not to implement green logistics and purchase traditional logistics, respectively.

4 Numerical simulation and simulation

Based on the evolutionary game model constructed above, the content of this section will use the ABM simulation method to simulate the evolutionary paths of enterprises implementing green logistics from the bottom to the top, from the perspective of micro-interaction to macro-emergence. This section uses Netlogo as a multi-agent simulation modeling tool to specifically simulate the influence of each player’s initial willingness to participate, the intensity of government subsidies and penalties, and the probability that the enterprise’s speculative behavior is founded on the evolutionary path and evolutionary results. Under the premise of meeting the basic requirements of the model, considering the actual situation and the principle of equality balance, let the initial parameters \( B_1 = 2, B_2 = 1, c = 7, T_1 = 8.5, T_2 = 10, R_1 = 4, R_2 = 3.5, s = 2, r = 2, A = 2, G = 5, K = 9, \theta = 5, v = 20, t = 7, \) and \( x_0 = y_0 = z_0 = 0.5 \), and \( x_0, y_0, z_0 \) respectively represent the proportion of the governments choosing to regulate in the initial stage, the proportion of logistics enterprises choosing to implement green logistics in the initial stage, and the proportion of users choosing to purchase green logistics in the initial stage. The magnitude relationship between each parameter value is consistent with the situation in 4 (b) of section 2.4; that is, to explore which parameters affect the final evolutionarily stable strategy of the system and the degree of influence.

4.1 The effect of enterprises’ initial willingness to participate on evolutionary results

Assuming other parameters remain unchanged, Figures 1 and 2 illustrate the impact of changes in users’ initial willingness on the system’s evolutionary results when the initial willingness of the government and enterprises are both 0.5. In Figure 1, when the initial willingness of the governments, enterprises, and users is all 0.5, the evolutionarily stable point of the system is \( E_1 = (0,0,0) \); that is, the governments choose not to regulate, and the enterprises and users choose not to implement green logistics and purchase traditional logistics, respectively.

When the user’s initial willingness increases to 0.9, the stable evolutionary result of the system changes, and the final evolutionarily stable point is \( E_4 = (0,1,1) \). This demonstrates that the change in users’ initial willingness has a greater impact on enterprises. As evident in Figure 2, when the proportion of users who are inclined to purchase green logistics is between 0.9 and 1, the proportion of enterprises inclined to implement green logistics grows slowly. When all users choose to purchase green logistics, the proportion of enterprises participating in the implementation of green logistics.
will increase sharply, demonstrating that when all users have established the concept of green consumption, it will greatly encourage enterprises to implement green logistics. Therefore, the government should increase the publicity of green logistics using news or network media. Only when the government’s publicity and advocacy are in place can the public and users truly understand the characteristics and advantages of green logistics, establish the concept of green consumption, and stimulate the market demand for green logistics. At the same time, it can also let logistics enterprises understand the government’s policies and regulations and guide enterprises to participate in logistics greening.

4.2 The effect of governments’ initial willingness to participate on evolutionary results

Assuming other parameters remain unchanged, Figures 1, 3, and 4 illustrate the impact of changing the government’s initial willingness to participate in the strategic choices of enterprises and users when the initial participation willingness of the enterprises and users is 0.5. As evident from Figures 3 and 4, when the government’s initial willingness to participate is 0.7 and above, the final evolutionarily stable point of the system is $E_1(0,1,1)$. As the government’s initial willingness increases, the time for enterprises and users to reach the evolutionarily stable strategy reduces, indicating that the government’s positive regulatory behavior can effectively motivate enterprises and users to choose environmentally friendly strategies.

From the three figures, the change of the government’s initial willingness to participate can effectively affect the strategic choice of enterprises and significantly shorten the time for enterprises to reach the evolutionarily stable point, but the time for users to reach the evolutionarily stable point in Figures 3 and 4 is not much different. This demonstrates that changes in the government’s initial willingness to participate have a greater impact on enterprises’ strategic choices.

4.3 The effect of users’ initial willingness to participate on evolutionary results

Assuming other parameters remain unchanged, Figures 1, 5, and 6 illustrate the impact of changing the initial participation willingness of enterprises on the strategic choice of the government and users when the initial participation willingness of the government and users is 0.5. When the initial willingness of enterprises to implement green logistics is 0.7 and above, the system reaches an evolutionarily stable state; that is, the government tends not to regulate, the enterprises tend to implement green logistics, and the users choose to purchase green logistics.

Comparing Figures 5 and 6 separately, we can see that the government’s willingness to choose to regulate in Figure 5 tends to decline after a period of growth, but in Figure 6, the government’s willingness to regulate has no upward trend but a direct and slow decline. This situation is what we hope to see; that is, when the initial willingness of enterprises to implement green logistics is large enough, there is no need for the government to regulate.

4.4 The effect of government subsidies to enterprises on the evolutionary results

Assuming other parameters remain unchanged, Figures 1, 7, and 8 illustrate the impact of changing the amount of green government subsidies to enterprises on the evolutionary results of the system. Figure 7, when the amount of government subsidies to enterprises increases by 35%, although the evolutionarily stable result of the system does not change, it has
played a certain incentive role for enterprises and users to choose green strategies. The willingness of enterprises to implement green logistics began to decline after a period of growth, and the decline of enterprises’ willingness to implement green logistics lags behind users, which demonstrates that when enterprises realize that the market of green logistics cannot develop and grow, they are unwilling to continue to implement green logistics at the risk of reducing profits, but immediately adjust their own strategies and choose not to implement green logistics.

However, due to the relatively small impact on enterprises under lower subsidies, it is difficult for enterprises to implement green logistics. When the subsidy amount is increased by 40%, the system will eventually stabilize in a state where enterprises implement green logistics and users purchase green logistics under the incentive of the government, demonstrating that higher subsidies have a great impact on the entire game system. Therefore, the government should invest more subsidies in the early stage to encourage enterprises to implement green logistics and form green logistics management.

4.5 The effect of government subsidies to users on the evolutionary results

Assuming other parameters remain unchanged, Figures 1, 9, and 10 illustrate that the evolutionary result of the system is affected by the intensity of government penalties. When the tax penalty amount is increased by 50%, the evolutionarily stable result of the system changes and stabilizes at point $E_i(0,1,1)$. With the increase of the government’s tax penalty, the speed of the strategy of enterprises and users to converge to 1 is also accelerated; that is, the government’s penalty can significantly affect the strategic choice of enterprises and has a greater impact on users. This is mainly because higher penalties can inhibit the speculative behavior of

4.6 The effect of government penalty on enterprises on evolutionary results

Figures 1, 11, and 12 illustrate that when other parameters remain unchanged, the evolutionarily stable result of the system is affected by the intensity of government penalties. When the tax penalty amount is increased by 50%, the evolutionarily stable result of the system changes and stabilizes at point $E_i(0,1,1)$. With the increase of the government’s tax penalty, the speed of the strategy of enterprises and users to converge to 1 is also accelerated; that is, the government’s penalty can significantly affect the strategic choice of enterprises and has a greater impact on users.
4.7 The effect of the probability of enterprises’ speculative behavior was founded on evolutionary results

Under the condition that other parameters remain unchanged, Figures 1, 13, and 14 illustrate the effect of the probability of an enterprise’s speculative being founded on the system’s evolutionarily stable results. When the probability of speculative behavior being founded increases from 0.5 to 0.6, the final strategic choice of enterprises and users changes, and both parties tend to choose environment-friendly strategies. Figures 13 and 14 indicates that the higher the probability of enterprises’ speculative behavior being founded, the shorter the time for enterprises and users to tend to an evolutionarily stable state. This demonstrates that the probability of an enterprise adopting speculative behaviors has a greater impact on the evolutionary results. Users can accurately identify whether the logistics they consume are green, which effectively reducing the enterprise’s speculative behavior. With the development of the economy, the public’s awareness of green issues is also increasing. To meet these needs, the government should formulate green logistics judgment standards as soon as possible to effectively inhibit the speculative behavior of enterprises in logistics greening, which will speed up the process of logistics greening.

5 Conclusion and Discussion

5.1 Research conclusions

Under the background of serious negative external factors in traditional logistics and the urgent need to develop green logistics, this paper takes the subjects involved in the process of logistics greening as the research object, constructs a tripartite evolutionary game model of the government, logistics enterprises, and users, and analyzes the evolutionarily stable strategy of each participant in different situations. Then, the Netlogo simulation tool is used to simulate the initial willingness of the three parties to participate, the intensity of government subsidies and penalties, and the probability that the enterprises adopt speculative behaviors to determine if they impact the evolutionary paths and results of the system. The following conclusions are drawn:

(1) The initial participation willingness of the government, logistics enterprises, and users have different effects on the evolutionary paths and results of the system. The simulation results demonstrate that the initial participation willingness of enterprises has a great influence on users’ strategic choices, while the strategic choice of enterprises is greatly affected by the initial willingness of the government and users to participate. The initial willingness of enterprises and users has an asymmetric impact, and enterprises are more sensitive to changes in users’ initial willingness to purchase green logistics. Therefore, the government should strengthen the publicity of green logistics, cultivate users’ preference for green logistics, expand the market demand for green logistics, and encourage enterprises to implement green logistics.

(2) Enterprises are more sensitive to government subsidies than users. The simulation results demonstrate that, based on the initial subsidy, users are willing to purchase green logistics only after the government subsidies to users increase by 50%, while the subsidies to enterprises only need to increase by 40% to make enterprises choose to implement green logistics. Moreover, only when government subsidies reach a high amount can they effectively motivate both enterprises and users to choose environment-friendly strategies. Therefore, when implementing a subsidy strategy, the government should fully consider the different effects of subsidies on enterprises and users and set a different amount of subsidies for enterprises and users to stimulate the subsidies that reflect the interests of both parties and speed up the process of greening logistics.

(3) The government’s tax penalties have an impact on both enterprises and users, and the stronger the government’s tax penalties, the more enterprises, and users tend to choose to implement green logistics and purchase green logistics, which demonstrates that tax penalties can effectively solve the problem of negative external factors of traditional logistics.
However, enterprises are more sensitive to government subsidies than tax penalties. The simulation results demonstrate that based on the initial subsidies and penalties, a 40% increase in government subsidies to enterprises can promote enterprises to change their strategy choices, while government tax penalties need to be increased by 50% to be effective. Therefore, when formulating policies, the government should consider the differences in the effects of these two subsidies and penalty measures.

(4) An important reason for the difficulty of developing green logistics is the speculative behavior of enterprises. While the speculative behavior of enterprises damages the interests of enterprises that implement green logistics and discourages enterprises that have not yet implemented green logistics from choosing this environment-friendly strategy, it also weakens users’ confidence in purchasing green logistics. Therefore, the higher the probability of being founded by the users after the enterprises adopt speculative behavior, the more the enterprises’ speculative behavior can be curbed. Given the rapid development of the economy and the increasing public awareness, the government should formulate criteria and an evaluation system of green logistics for enterprises so that users can accurately identify green logistics and traditional logistics and suppress the speculative behavior of enterprises in the process of greening logistics.

5.2 Implication, Limitation and Prospect

Under the new normal of China’s economic development, future research should focus on the national green development strategy and clarify the development goals of the transformation from a traditional logistics industry to the green logistics industry and regional green development. By examining the theory and policy research of green logistics to promote green development, this paper analyzed the characteristics and deficiencies of existing research, identified obstacles in the implementation of green logistics in China’s logistics enterprises, and proposed corresponding solutions to promote the development of green logistics in enterprises.

This paper analyzed the three-party strategy choice in logistics greening from the perspective of a theoretical model. A numerical simulation under the established parameters was carried out, which has a certain deviation from the actual situation. Therefore, the conclusions will be more convincing if the actual data can be obtained to simulate the theoretical model.

In addition, this paper mainly studied the strategic choice of each participant under a static subsidies and penalties mechanism and the influence of relevant parameters on each player’s behavioral choice, which can further study the situation under the dynamic subsidies and penalties mechanism. Finally, when using evolutionary game theory to explore the problem of green logistics, we can also consider other participants related to the green process of logistics.

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Conflict of interest

The authors declare that they have no conflict of interest.

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