Evolutionary Game Analysis of Expressageage Packaging in the Process of Recycling

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Abstract. We take emerging recycling expressageage packaging as the breakthrough point, and construct the evolutionary game model between the electric business enterprise and the third party recycling enterprises, what's more, explore the game strategy selection and evolution trend. The results show that: recovery coefficient, government subsidy, cooperation cost and reward level have a significant impact on the game strategy selection and evolution results. Based on this, relevant suggestions are put forward.

1. Introduction

The volume of China's express business has been greatly increased. Meanwhile, the waste of expressage packaging resources and environmental pollution are more and more serious. Several Chinese ecommerce companies have gradually introduced its own characteristic green expressage packaging. This is worthy of attention is that Jingdong's "green box" green flow box recycling, for the first time adopted the industry's new recycling system. Recycling, disinfecting, cleaning and reshaping from site to warehouse are all handled by dedicated partners. The introduction of third-party recycling agencies is an innovation for the expressage packaging recycling industry, but there are still many uncertainties that affect the construction of expressage packaging recycling systems. Whether e-commerce companies and third-party recycling companies can achieve stable cooperation during the construction of the future expressage packaging recycling system, and where the operating model of the recycling system evolves, and whether e-commerce companies and third-party companies can eventually form a synergy. The construction of courier expressage packaging and recycling system has become a theoretical and practical problem that needs to be solved.

For the new things in the expressage packaging industry, there are few scholars to study the new things, and the existing literature is mostly based on qualitative methods to conduct some theoretical discussion. For instance, Yi Zou and Yuqin Li built an expressage packaging recycling system based on the 3R principle of circular economy theory, and put forward the basic conditions and safeguard measures needed to ensure the smooth operation of the system and put forward some suggestions from the perspective of the government, enterprises and consumers[1]. Lei Zhu and Mengxi Lo constructed a circular packaging sharing system based on shared circular packaging, and expounded and compared the three recycling methods under the purchase mode and the lease mode, namely autonomous recovery, joint recovery and entrustment recovery[2].
This article will discuss the cooperation strategy choice between e-commerce companies and third-party recycling companies in the process of expressage recycling packaging recycling. Evolutionary game theory is a theoretical method of dynamic game theory[3]. Evolutionary game theory takes the behavior of bounded rational groups as the research object and plays a very good role in the evolutionary game of species in biology. The evolution of individual individuals in the group requires a long process of evolution[4] and eventually converges to a stable state, which has been widely used in the field of economic management[5]. It is more realistic to use evolutionary game theory to study the strategic equilibrium of the cooperation between the e-commerce enterprises and the third party recycling enterprises, whether it is the electronic business enterprise or the third party recycling enterprise, which is not very consistent with the complete rational hypothesis in the traditional game theory. This paper will use evolutionary game theory to discuss the cooperation between the e-commerce enterprises and the third party recycling enterprises in the process of expressage recycling packaging, analyze the influencing factors of the two parties, explore the strategy evolution of both parties in the process of recycling, and provide a theoretical reference for the establishment of the expressage packaging recovery system.

2. Hypothesis and Model

Electric business enterprises and the third party recycling enterprises cooperate to jointly develop the recycling service of expressage delivery business. They constantly adjust their strategies through their own learning, and ultimately achieve a balanced solution. Based on this, the following assumptions are made:

- The probability of cooperation strategy is \( x \), and the probability of adopting non-cooperative strategy is \( 1-x \). The probability of third party recycling enterprises to adopt cooperative strategy is \( y \), and the probability of adopting non-cooperative strategy is \( 1-y \).

- When both sides do not adopt the cooperative strategy, that is, the electronic business enterprise reclaims the expressage cycle packaging independently, although it can not benefit in the short term, it will achieve considerable circular economic benefits in the long run, such as the promotion of the corporate image and the savings of a large amount of purchase of packaging funds for the development of the enterprise. In its ideal state, the recycling economic returns of the expressage recycling packaging are recorded as \( R_1 \). Because it is difficult to recover all of them in reality, the recovery coefficient \( a (0<a<1) \) is introduced. The product of the \( R_1 \) is the circular economic benefit obtained by the business enterprise, and the cost of the recovery business is \( C_1 \). In addition, the government's subsidy to the recycling business of expressage delivery business is recorded as \( R_s \). The third party recycling enterprises do not involve the recycling of expressage delivery packagings, their normal return is \( R_2 \), and the operation cost is \( C_2 \).

- When both sides adopt a cooperative strategy, the two sides are jointly responsible for the recycling packaging. At this time, the circular economic benefits obtained by the e-commerce enterprises are recorded as \( R_1' \). The e-commerce enterprises can save some manpower and material resources by cooperation, and can be used in other aspects of the development of enterprises. The efficiency of circular economy also includes the excess income from cooperation. Assuming that government subsidies and recovery coefficients remain unchanged, they are still \( R_s \) and \( a \). In addition to the income \( R_2 \) and the cost \( C_1 \) obtained by the normal business, the third party recycling enterprises receive the remuneration of \( R_3 \) and the subsidies given by the government when they participate in the cooperation. The total cost of the two sides’ cooperation to carry out the recovery business is \( C \), and the cost sharing coefficient is \( b (0<b<1) \).

- When the business enterprises and the third party recycling enterprises take different strategies, the cooperative side will produce a certain cost of effort because of the effort to achieve the coordination expectation. The cost of the efforts of the e-commerce enterprises and the third party recycling enterprises is \( L_1 \) and \( L_2 \) respectively.

Based on the above assumptions, we establish a game payment matrix for the electric business enterprise and the third-party recycling companies on recycling of expressage returnable packaging.
Table 1 Game Payment Matrix for E-Commerce Companies and Third-party Recycling Companies

| E-commerce companies | Third-party recycling companies |
|----------------------|-------------------------------|
| **Cooperation**      | **Noncooperation**             |
| Cooperation          | \( aR_1 + R_c - bC - R_3 \)   |
|                      | \( R_2 + R_3 + C_2 - (1-b)C \) |
| Noncooperation       | \( aR_1 + R_c - C_1 \)        |
|                      | \( R_2 - C_2 - L_2 \)         |

3. Evolutionary Game Analysis

3.1 Equilibrium Point of Evolutionary Game

From the above assumptions and the game payment matrix, we can see that for electric business enterprises, their adaptability of choice of cooperation strategy is:

\[
U_{H1} = y(aR_t + R_c - bC - R_3) + (1 - y)(aR_t + R_c - C_1 - L_1)
\]

The adaptability of electric business enterprises to choose non cooperative strategy is:

\[
U_{H2} = y(aR_t + R_c - C_1) + (1 - y)(aR_t + R_c - C_1)
\]

The average adaptability of e-commerce enterprises is as follows:

\[
U_{H} = \frac{U_{H1} + U_{H2}}{2}
\]

We get the replication dynamic equation of cooperation strategy for electric business enterprises:

\[
F'(x) = \frac{dx}{dt} = x(U_{H1} - U_{H1})
\]

Similarly, the replicated dynamic equation of third party recycling enterprises implementing cooperative strategy is:

\[
F'(y) = \frac{dy}{dt} = y(U_{H2} - U_{H2})
\]

Set \( F'(x) = 0 \) and \( F'(y) = 0 \), thus:

\[
x_1 = 0, x_2 = 1, y^* = \frac{L_1}{aR_t + C_1 + L_1 - aR_t - bC - R_3}
\]

Or:

\[
y_1 = 0, y_2 = 1, x^* = \frac{L_2}{R_2 + R_3 + L_2 - (1-b)C}
\]

Based on the analysis of duplication dynamic equation of electric business enterprises and third party recycling enterprises, five local equilibrium points of the system are obtained: \((0,0), (0,1), (1,0), (1,1)\) and \((x^*, y^*)\). The first four are the pure strategy equilibrium points, and the last one is the mixed strategy equilibrium point.

3.2 Analysis of Equilibrium Point

The stability of the dynamic system equilibrium point can be judged by the determinant of the Jacobi matrix of the dynamic system and the symbol of trace. The Jacobian matrix is obtained by finding the partial derivative of the dynamic equation of the replicator[6]. The Jacoby matrix \( J \) and its
corresponding determinant \( \det J \) can be obtained by the replication dynamic equation of the cooperation strategy between the electric business enterprise and the third party recycling enterprise.

\[
J = \begin{bmatrix}
(l - 2x)[y(aR'_1 + C_1 + L_1 - aR_1 - bC - R_3) - L_1] \\
y(l - y)[R_1 + R'_1 + L_2 - (1 - b)C] \\
x(1 - x)(aR'_1 + C_1 + L_1 - aR_1 - bC - R_3) \\
(1 - 2y)[x(R_1 + R'_1 + L_2 - (1 - b)C) - L_2]
\end{bmatrix}
\]

(1)

\[
\det J = (1 - 2x)(1 - 2y)[y(aR'_1 + C_1 + L_1 - aR_1 - bC - R_3) - L_1]
\]

\[
[x(R_3 + R'_3 + L_2 - (1 - b)C) - L_2] - xy(1 - x)(1 - y)[R_3 + R'_3 + L_2 - (1 - b)C][aR'_1 + C_1 + L_1 - aR_1 - bC - R_3]
\]

(2)

\[
tr J = (1 - 2x)[y(aR'_1 + C_1 + L_1 - aR_1 - bC - R_3) - L_1]
\]

\[
+(1 - 2y)[x(R_3 + R'_3 + L_2 - (1 - b)C) - L_2]
\]

(3)

5 local equilibrium points are brought into \( \det J \) and \( tr J \), and the results are shown in Table 2.

### Table 2 Determinant and trace of local equilibrium point

| Equilibrium point | \( \det J \)                  | \( tr J \)                  |
|-------------------|-------------------------------|-----------------------------|
| (0,0)             | \( L_1L_2 \)                  | \(- (L_1 + L_2) \)          |
| (0,1)             | \( L_3(aR'_1 + C_1 - aR_1 - bC - R_3) \) | \( L_2 + (aR'_1 + C_1 - aR_1 - bC - R_3) \) |
| (1,0)             | \( L_1[R_3 + R'_3 - (1 - b)C] \) | \( L_1 + [R_3 + R'_3 - (1 - b)C] \) |
| (1,1)             | \( (aR'_1 + C_1 - aR_1 - bC - R_3)[R_3 + R'_3 - (1 - b)C] \) | \( aR'_1 + C_1 - aR_1 - bC - R_3 \) |
| \((x^*, y^*)\)    | \( (aR'_1 + C_1 - aR_1 - bC - R_3)[R_3 + R'_3 - (1 - b)C] \) | \( aR'_1 + C_1 - aR_1 - bC - R_3 \) |

At point \((0,0)\), \( L_1L_2 > 0, -(L_1 + L_2) < 0 \) is right for all \( L_1 \) and \( L_2 \), namely \( \det J > 0, tr J < 0 \). Point \((0,0)\) is an evolutionary stable strategy (ESS). Whether the other four equilibrium points are ESS depends on the symbols of \( aR'_1 + C_1 - aR_1 - bC - R_3 \) and \( R_3 + R'_3 - (1 - b)C \). Next, we will discuss the stability of all equilibria in 4 cases. In each case, the stability analysis of each equilibrium point is shown in table 3 to table 6. The dynamic phase diagram of system evolution is shown in Figure 1 to Figure 4.

### Table 3 Local stability analysis of an equilibrium point in case 1

| Equilibrium point | \( \det J \) | \( tr J \) | Stability       |
|-------------------|-------------|-------------|----------------|
| \((0, 0)\)        | +           | -           | ESS (Stable)   |
| \((0, 1)\)        | +           | +           | Unstable       |
| \((1, 0)\)        | +           | +           | Unstable       |
| \((1, 1)\)        | +           | -           | ESS (Stable)   |
| \((x^*, y^*)\)    | +           | 0           | Saddle Point   |
Table 4  Local stability analysis of a equilibrium point in case 2

| Equilibrium point | det J | tr J | Stability       |
|-------------------|-------|------|-----------------|
| (0, 0)            | +     | -    | ESS (Stable)    |
| (0, 1)            | +     | -    | Unstable        |
| (1, 0)            | -     | Uncertain | Saddle Point |
| (1, 1)            | -     | Uncertain | Saddle Point |

Table 5  Local stability analysis of a equilibrium point in case 3

| Equilibrium point | det J | tr J | Stability       |
|-------------------|-------|------|-----------------|
| (0, 0)            | +     | -    | ESS (Stable)    |
| (0, 1)            | -     | Uncertain | Saddle Point |
| (1, 0)            | +     | +    | Unstable        |
| (1, 1)            | -     | Uncertain | Saddle Point |

Table 6  Local stability analysis of a equilibrium point in case 4

| Equilibrium point | det J | tr J | Stability       |
|-------------------|-------|------|-----------------|
| (0, 0)            | +     | -    | ESS (Stable)    |
| (0, 1)            | -     | Uncertain | Saddle Point |
| (1, 0)            | -     | Uncertain | Saddle Point |
| (1, 1)            | +     | +    | Unstable        |

Figure 1. Dynamic phase diagram of system evolution in case 1
In case 1, \( aR_1' + C_1 - aR_1 - bC - R_3 > 0 \) and \( R_3 + R_s' - (1 - b)C > 0 \). This is a system consisting of two unstable points B, C and a saddle point E is bounded by BEC. When the game state is located in the region BECD, the final evolution result will converge to the strategy combination (cooperation, noncooperation). At this time, both the e-commerce enterprises and the third party recycling enterprises reach a win-win ideal state. When the game state is located in the region ABEC, the evolutionary results will be converged in the strategy combination (noncooperation, noncooperation). That is, the behavior of the e-commerce enterprises and the third party recycling enterprise is determined by the location of saddle point E. The change of E location determines whether the two sides cooperate. In order to get the ideal combination of strategy (cooperation, cooperation), we need to expand region BECD and reduce ABEC as far as possible. The value of \( x^* \) and \( y^* \) should be smaller in order to make the saddle point E position as close as possible to the bottom left side of the phase diagram. From the value of each parameter, e-commerce enterprises and third party recycling enterprises reduce the cost of cooperation recovery operation, as far as possible through various incentives to improve the rate of expressage recycling packaging recovery, the government to improve the subsidy of third party enterprises to participate in the recovery business will make the value of \( x^* \) and \( y^* \) smaller.

![Dynamic phase diagram of system evolution in case 2.](image)

In case 2, \( aR_1' + C_1 - aR_1 - bC - R_3 > 0 \) and \( R_3 + R_s' - (1 - b)C < 0 \). The equilibrium point of the system is A (0,0), B (0,1), C (1,0), D (1,1), and the ESS of the system is (0,0), and the corresponding evolutionary stabilization strategy is (noncooperation, noncooperation). Whether the e-commerce enterprises chooses cooperation or noncooperation strategy, its excess revenue from the expressage circular packaging recycling business is greater than the cost it allocated. However, no matter what kind of choice is made by the business enterprise, the income of the third party recycling enterprise is not enough to exceed the cost of the\((1-b)C\). In the long-term evolution process, the third party recycling enterprise will choose the noncooperation strategy out of its own interests, which is the best strategy of the third party recycling enterprise, this is the situation that e-commerce enterprises are not willing to see. Therefore, e-commerce enterprises can appropriately help third party recycling enterprises improve management level, determine reasonable income and cost sharing ratio, and the government can improve the level of subsidies, and encourage the third party recycling enterprises to participate in the construction of expressage recycling packaging recovery system.

In case 3, the equilibrium points of the system are A (0,0), B (0,1), C (1,0), D (1,1), and the ESS of the system is (0,0), and the corresponding evolutionary stabilization strategy is (noncooperation, noncooperation). At this time, the third party recycling enterprises participate in the expressage returnable packaging recovery business from the e-commerce enterprises to obtain higher remuneration and can obtain certain subsidies from the government, and the cost is low, so it tends to participate in the recycling packaging of expressage recycling business. But these are only an icing on the cake for e-commerce enterprises. At this time, e-commerce enterprises, because of the cost of their choice of cooperation \( R_3 + bC \) is higher than the excess returns \( a(R_1' - R_1) \), so they tend to choose not
to cooperate, rely on themselves to carry out the recycling packaging, the final system will be stable strategy (cooperation, noncooperation) to evolve.

![Figure 3. Dynamic phase diagram of system evolution in case 3.](image)

In case 4, the equilibrium point of the system is A (0,0), B (0,1), C (1,0), D (1,1), and the ESS is (0,0), and the corresponding evolutionary stabilization strategy is (noncooperation, noncooperation). The equilibrium point (1,1), namely (cooperation, cooperation) strategy, has become the unstable point of the system. Because e-commerce enterprises and the third party recycling enterprises have smaller income, their invest more costs. The cooperation between the two parties can only be insolvent, which may be caused by the low recovery rate and the insufficient government subsidies. After a long-term game, the two sides will choose noncooperation strategy.

![Figure 4. Dynamic phase diagram of system evolution in case 4.](image)

4. Conclusion
Based on the hypothesis of limited rationality, this paper constructs the evolutionary game model of two main types, e-commerce enterprises and third party recycling enterprises in the process of expressage cycle packaging recovery. The results show that the recycling coefficient, compensation paid by e-commerce companies to third-party recycling companies, government subsidies and the cost of cooperation has played a crucial role in the strategic choices of both parties and the evolution of the system. In view of this, in order to better establish a perfect recycling recycling system and promote the formation of multi cooperative recycling system, the following suggestions are put forward in this paper.

- Government and electric business enterprises need to step up efforts to guide consumers to participate in the expressage recycling packaging recycling. The recovery rate directly affects the profitability of the recovery business. The government should encourage consumers to take part in the recycling of expressage packaging, educate the consumers and train their awareness and habits of the
expressage packaging. E-commerce enterprises can carry out green consumption activities, through integral reward, reduction of postage, coupons and other means, according to the different packaging and pricing, the establishment of integral feedback, green credit and other mechanisms to guide consumers to participate in the expressage packaging recovery, so that not only can improve the return yield to improve the recycling economic returns, but also set a good social image of the enterprise.

- The government should introduce appropriate subsidy policies to promote the establishment of multi-party collaborative packaging system for expressage delivery. The level of government subsidies has a significant impact on whether the business enterprises and the third party recycling enterprises can cooperate to carry out the recycling packaging recycling. When the level of subsidies is higher, the more the system will evolve towards the direction of cooperation. The future of the expressage packaging recovery system is not clear. Only in the case of profit, the enterprise will actively participate in the recovery of the expressage cycle packaging. Therefore, the government should introduce appropriate subsidy policy to make the enterprise have reasonable income, so that the enterprise has enough power to participate in the establishment of the recovery system.

- The cost of cooperative operation should be reduced and the appropriate revenue sharing mechanism should be determined. The cooperation cost and the remuneration level are the influence factors that directly affect the cooperation between the e-commerce enterprises and the third party recycling enterprises. All sides should maintain full coordination, determine the appropriate cost sharing and share sharing ratio, thus reduce the overall cooperation cost in order to promote the establishment of multi cooperative and cooperative packaging recovery system. Returnable containers manufacturers should design more environmentally friendly and lower cost packaging and reduce overall cost inputs.

The limitation of this paper is mainly to consider the two main bodies of the process of recycling. The construction of the actual recovery system also includes the government, the consumer, the packaging production enterprise and so on. In the future, the evolution game model of the expressage cycle packaging is extended to the three dimensional and multi-dimensional subject, and the strategy selection and the system evolution trend of the multi-dimensional subject participation are explored.

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