# Evolutionary Game Research on the Recovery of Waste Electronic Products

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## Abstract

The wave of "Internet +" has spawned the emergence of O2O recycling methods, which has caused the traditional recycling pattern to begin to change. The advantages of O2O recycling is more green and environmentally friendly, which is conducive to the formation of formal recycling channels, making O2O recycling a major trend. In addition, in recent years, with the popularization of the concept of "green consumption", consumers have begun to be divided into green consumers and traditional consumers, and the two have different differences in their willingness to recycle, which will also have a certain impact on the recycling process. Therefore, considering the market mechanism, this paper takes remanufacturing enterprises as the main body of recycling, based on the theory of evolutionary game, and constructs the evolutionary game model of "remanufacturing enterprise-consumer" from the perspective of the synergistic evolution of stakeholders involved in recycling. Analyze the impact of re-manufacturing companies and consumers on their respective choices in the recycling process. Analyze the evolutionary stability strategy and evolution law of remanufacturing enterprises and consumers by solving the dynamic equations of replication. Finally, the model is simulated by Matlab software to verify its effectiveness. The final research results show that: (1) the remanufacturing enterprise's recycling strategy and the consumer's choice strategy will affect each other. (2) Due to the incomplete rationality of the two systems, the initial state does not choose the optimal strategy, but the system Eventually, it will form an ideal state (re-manufacturing companies use O2O for recycling, consumers evolve into green consumers) or non-ideal states (remanufacturing companies use traditional methods for recycling, consumers evolve into traditional consumers). (3)Reducing the logistics costs of producers using O2O recycling and increasing the recycling price for green consumers will speed up the evolution of the system to an ideal state. But increasing the willingness of the average consumer to recycle will increase the probability that the system will evolve into a non-ideal state.

## Keywords

Waste electronic product recycling ,Evolution game, Matlab.

## 1. Introduction

In recent years, under the wave of "Internet +", O2O (Online to offline) recycling methods such as "Love Recycling" and "Recycling Brother" came into being, and the industrial pattern of recycling and recycling of used electronic products began to change gradually. The O2O recycling method is environmentally friendly and efficient. And the service is convenient, which is conducive to the formation of a formal recycling channel, so it is bound to become a trend. However, due to the high cost of recycling and the high technical threshold and short industrial chain, the current O2O recycling scale is not large. The traditional recycling method is face-to-face trading, which is in line with the characteristics of the recycling industry and is also in line with consumer spending habits. However, it takes time and effort, there are many intermediate links, and the service process is difficult to trace. Therefore, the coexistence of traditional recycling and O2O recycling is still the main way of recycling in the manufacturing industry at this stage. In addition, the influence of consumers' green behavior characteristics on manufacturing enterprises' recycling and remanufacturing decisions has also received more and more attention from scholars. Shaofu Du and Wenzhi Tang[1], when researching enterprise production, subdivided consumers into “green consumers” and “traditional consumers”, and guided the production and market segmentation by consumers. Green consumers tend to buy green products when they purchase products, and pay attention to the disposal of garbage, and have a high awareness of recycling. In this context, the influence of consumers' green behavior differentiation on recycling methods of recycling enterprises and how external factors will affect the evolution of recycling methods of recyclers are all worthy of study.

At present, some scholars have started discussions on different aspects of the recycling of waste electronic products. Mainly from the recycling channels, consumer recycling awareness and other aspects of the analysis and discussion. In terms of recycling channels, Du Zhiping and Wang Xiaoqiang[2] built a recycling model of used mobile phones based on manufacturers based on O2O method, and discussed the relationship between factors such as recycling price and recycling volume and manufacturers' profit. Kaiji, Yang Jinyun[3] established a recycling system for used household appliances based on O2O for the confusion of recycling channels and low recycling awareness, and improved recycling efficiency. Lipan Feng, Kannan Govindan[4] and others considered the retrograde supply chain with dual recycling channels, considering the recycling of waste electrical and electronic products in three different situations: single traditional recycling channel, single online recycling channel and mixed dual recycling channel. The results show that the hybrid channel is always better than the single channel recycling. Wen Xiaoqin[5] constructed the models of manufacturer recycling, retailer recycling and third-party logistics recycling for the recycling of waste products, and conducted comparative analysis. Finally, when the manufacturers considered social responsibility more and the government subsidies were higher, the producers will choose to recycle independently. Xu Hong, Wang Hui[6], etc., through the evolutionary game model of express delivery enterprises and consumers under the market mechanism, it is concluded that the express delivery enterprises will eventually choose to build a recycling industry chain to recycle express waste.

In the research on the heterogeneity of consumer recycling awareness, Mu Yanfen and Nie Jiajia[7] classified consumers, and on this basis, studied the strategic choices of manufacturers under different recycling regulations, and demonstrated the recycling of products. The more sensitive consumers, the higher the recycling factor of the product. Yi Yuzhen and Yang Xiao dong[8] considered the heterogeneous willingness of consumers to pay for new products and remanufactured products, and constructed a contract model for third-party recycling, which solved and derived the heterogeneous consumer contract model influences. Li Chunfa and Feng Lipan[9] constructed a recycling model based on consumer recycling behavior preferences, and analyzed the impact of consumer preferences on recycling channel strategies in different situations. Xiong zhong yu and Liang Xiao ping[10] considered the recycling consciousness of consumers in product recycling, established a game model for different subjects to recover. And analyzed the impact of consumers' recycling awareness on the optimal solution; Zong Gang and Wei Suhao[11] based on consumption The recycling consciousness establishes the waste clothing resource economy model of the enterprise's independent recycling mode and the third-party recycling mode, and makes a comparative analysis. The results show that there are optimal solutions for both channels.

Previous studies have achieved some results in recycling, but there are still some limitations. First, the joint role of recycling types and consumer types in remanufacturing companies cannot be considered together. On the basis of considering the type of recycling of remanufacturing enterprises, the impact of different consumer types on recycling decisions of remanufacturing enterprises is analyzed. Secondly, the proportion of manufacturing enterprises that adopt different recycling methods and the recycling costs of manufacturing enterprises have not been considered from a dynamic perspective. The situation of the system evolution game in the case. Therefore, based on the heterogeneous behavior of consumers' green behavior, this paper constructs a game model dominated by remanufacturing enterprises and participates in consumers. From the perspective of evolutionary game, this paper analyzes the factors such as recycling cost, recycling price and consumer awareness. Impact.

## 2. Parameter setting and model assumptions

Under the market mechanism, the existing recycling methods of remanufacturing companies coexist in the two ways of offline recycling and O2O recycling. Since the remanufacturing enterprises have begun to use the O2O method for recycling, this paper does not consider the cost of building O2O in the early stage of remanufacturing enterprises. However, considering the actual recycling process, the O2O method is more expensive than the traditional way of recycling. In addition, among the consumer groups, there are traditional consumers and green consumers. We refer to consumers who purchase general products in the early stage as traditional consumers, and consumers who purchase green products as green consumers, but both consumers participate. Recycling, but the willingness to participate in recycling is different, green consumers are more willing to recycle than traditional consumers, Moreover, in order to encourage traditional consumers to participate in recycling, the recycling price paid by the remanufacturing company to the traditional consumer is slightly higher than the recycling price paid to the green consumer. The remanufacturing company recycles the product from the consumer, reprocesses it, and resells it. Assume that the remanufactured product is of the same quality and the same price. The rest of the system parameters are set as follows:

$\theta_1$: The willingness of traditional consumers to recycle;

$\theta_2$: The willingness of green consumers to recycle;

$P_1$: The recycling price paid by the remanufacturing company to traditional consumers;

$P_2$: The recycling price paid by the remanufacturing company to the green consumer;

$P$: The sales price of the recycled product after remanufacturing;

$K_L$: The additional benefits that traditional consumers choose to participate in O2O recycling (psychological satisfaction and time cost savings); $K_h$: Green consumers choose to participate in the extra income obtained by O2O recycling (psychological satisfaction and time cost of saving, etc.);

$a+bP_i(i=1,2)$: The amount of recycling that remanufacturing companies use when recycling in the traditional way;

$G$: The impact of online evaluations visible to remanufacturing companies using the O2O method of recycling;

$a+bP_i+\theta_i G(i=1,2)$: The amount of recycling that remanufacturing companies use when recycling by O2O;

$c$: The cost of a single transaction generated by remanufacturing companies using O2O recycling.

From the consumer level, in addition to the recovery price that consumers can obtain in the process of recycling, the utility theory in consumer theory points out the satisfaction that consumers get when they consume goods, that is, the utility obtained by consumers can also be measured. Calculate the producer's income function and the consumer's utility function separately. The income payment function matrix of producers and consumers is shown in Table 1:

Table 1 Producer and consumer income function matrix

| Remanufacturing company / consumer | Offline recycling | O2O recycling |
|---|---|---|
| Traditional consumer | $\theta_1+P_1$ , $\theta_1(a+bP_1)$(P-P$_1$) | $(1+K_L)\theta_1+P_1$ , $\theta_1(a+bP_1+$G)(P-P$_1$-$c$) |
| Green consumer | $\theta_2+P_2$ , $\theta_2(a+bP_2)$(P-P$_2$) | $(1+K_h)\theta_2+P_2$ , $\theta_2(a+bP_2+$G)(P-P$_2$-$c$) |

## 3. Evolutionary game strategy analysis

Analysis of Evolutionary Stability Strategy of Remanufacturing Enterprises

It is assumed here that the proportion of remanufacturing companies using offline recycling is $x$ The ratio of recycling by O2O method is $1-x$ 。In the consumer group, the proportion of traditional consumers is $y$ The proportion of green consumers is $1-y$ 。The profit function of the remanufacturing company using the offline recycling method and the O2O mode recycling are as follows: Evolutionary game strategy analysis

$$U_1=y\theta_1(a+bP_1)(P-P_1)+(1-y)\theta_2(a+bP_2)(P-P_2) \quad (1)$$

$$U_2=y\theta_1(a+bP_1+G)(P-P_1-c)+\theta_2(1-y)(a+bP_2+G)(P-P_2-c) \quad (2)$$

The average revenue of a remanufacturing company is:

$$U=xU_1+(1-x)U_2 \quad (3)$$

The replication dynamic equation of a remanufacturing enterprise is:

$$F(x)=\frac{dx}{dy}=x(1-x)(U_1-U_2)$$
$$=F(x)=x(1-x)\{y[\theta_2G(P-P_2-c)+\theta_1G(P-P_1-c)-\theta_2c(a+bP_2)-\theta_1c(a+bP_1)]$$
$$-\theta_2G(P-P_2-c)+\theta_2c(a+bP_2)\} \quad (4)$$

Finding the first derivative of equation (4) gives:

$$F'(x)=(1-2x)\{y[\theta_2G(P-P_2-c)+\theta_1G(P-P_1-c)-\theta_2c(a+bP_2)-\theta_1c(a+bP_1)]$$
$$-\theta_2G(P-P_2-c)+\theta_2c(a+bP_2)\} \quad (5)$$

According to the relevant theory of evolutionary game, when $F(x)=0, F'(x)<0$ Time, $x$ A stable strategy for the evolution of the system. Therefore $F(x)=0$, by solving the possible stability points of the system $x=0$ or $x=1$ or

$$y^*=\frac{\theta_2G(P-P_2-c)-\theta_2c(a+bP_2)}{\theta_2G(P-P_2)-\theta_1G(P-P_1)-\theta_2c(a+bP_2+G)+\theta_1c(a+bP_1+G)},$$

The following is an analysis of the producer's behavioral strategy choices when y is in different ranges of values.

when $y=\dfrac{\theta_2G(P-P_2\text{-}c)-\theta_2c(a+bP_2)}{\theta_2G(P-P_2-c)-\theta_1G(P-P_1-c)+\theta_1c(a+bP_1)-\theta_2c(a+bP_2)}$ , $F(y)=0$ , $F'(y)=0$ At this time for $y$ ,for the axis, it is stable. That is, the proportion of traditional consumers in the consumer group is $\frac{\theta_2 G(P-P_2\text{-}c)-\theta_2 c(a+bP_2)}{\theta_2 G(P-P_2-c)-\theta_1 G(P-P_1-c)+\theta_1 c(a+bP_1)-\theta_2 c(a+bP_2)}$ When remanufacturing companies use traditional methods to recover used electronic products, the probability is certain.

When $y>\frac{\theta_2 G(P-P_2\text{-}c)-\theta_2 c(a+bP_2)}{\theta_2 G(P-P_2-c)-\theta_1 G(P-P_1-c)+\theta_1 c(a+bP_1)-\theta_2 c(a+bP_2)}$ .When there is $F'(1)<0$ , at this time, $x=1$.A globally unique evolutionary stability strategy point. That is to say, when the proportion of traditional consumers in the consumer group is as high as a certain degree, it is the optimal strategy for the remanufacturing enterprise to choose to use the traditional offline recycling method.

When $y<\frac{\theta_2 G(P-P_2\text{-}c)-\theta_2 c(a+bP_2)}{\theta_2 G(P-P_2-c)-\theta_1 G(P-P_1-c)+\theta_1 c(a+bP_1)-\theta_2 c(a+bP_2)}$ .When there is $F'(0)<0$ 。At this time $x=0$, the only evolutionary strategy point for the global evolution. When the proportion of green consumers increases to a certain extent, it is the optimal strategy for remanufacturing companies to choose to use O2O recycling.

(2)Analysis of consumer evolutionary stability strategy

For the consumer group, the income function of traditional consumers and green consumers are:

$$V_1 = x(\theta_1+P_1)+(1-x)[(1+K_L)\theta_1+P_1] \tag{6}$$

$$V_1 = x(\theta_2+P_2)+(1-x)[(1+K_h)\theta_2+P_2] \tag{7}$$

The average income of the consumer group is:

$$V = yV_1+(1-y)V_2 \tag{8}$$

The dynamic equation of replication for the consumer group is:

$$\begin{aligned} F(y) &= \frac{dy}{dt} = y(1-y)(V_1-V_2) \\ &= y(1-y)[x(K_h\theta_2-K_L\theta_1)+(1+K_L)\theta_1+P_1-(1+K_h)\theta_2-P_2] \end{aligned} \tag{9}$$

Solving the first derivative of equation (9) gives:

$$F'(y)=(1-2y)[x(K_h\theta_2-K_L\theta_1)+(1+K_L)\theta_1+P_1-(1+K_h)\theta_2-P_2] \tag{10}$$

make $F(y)=0$ , the possible balance point of the system is: $y=0$ or 1 , $x^*=\frac{(1+K_h)\theta_2+P_2-(1+K_L)\theta_1-P_1}{K_h\theta_2-K_L\theta_1}$ .The following is an analysis of the best strategies for consumer groups when x is in different ranges of values.

When $x=\frac{(1+K_h)\theta_2+P_2-(1+K_L)\theta_1-P_1}{K_h\theta_2-K_L\theta_1}$ , When there I, $F(x)=0$ , $F'(x)=0$ ,the proportion of traditional consumers in the consumer group is stable.

When $x>\frac{(1+K_h)\theta_2+P_2-(1+K_L)\theta_1-P_1}{K_h\theta_2-K_L\theta_1}$ , When there is $F'(1)<0$, that is to say $x=1$.It is the only evolutionary stability strategy of the whole. That is, when the proportion of remanufacturing companies using traditional methods to recover is as high as a certain degree, consumers will choose to become traditional consumers will be the optimal strategy.

When $x<\frac{(1+K_h)\theta_2+P_2-(1+K_L)\theta_1-P_1}{K_h\theta_2-K_L\theta_1}$ , When there is $F'(0)<0$ , which is $x=0$ .It is the only evolutionary stability strategy of the whole. That is, when the proportion of remanufacturing companies using the O2O method to recover is as high as a certain degree, it is the best strategy for consumers to choose to evolve into green consumers.

(3)Evolutionary game parameter analysis

The replica dynamic system of the model can be composed of equations (4) and (9). Let equations (4) and (9) be equal to 0, so that five local equilibrium points of the system can be calculated, respectively (0, 0). (0,1),(1,0),(1,1),(x*,y*); where the first four points are purely strategic equilibrium points, and the fifth point is the mixed strategy equilibrium point, remanufacturing enterprise The evolutionary equilibrium point stability of the dynamic system composed of the consumer group can be obtained by analyzing the local stability of the Jacobian matrix of the replication dynamic equation. Jacques matrix *J* for:

$$J=\begin{bmatrix} (1-2x)\{y[\theta_2 G(P-P_2-c)-\theta_2 c(a+bP_2) & x(1-x)[\theta_2 G(P-P_2)-\theta_1 G(P-P_1) \\ -\theta_1 G(P-P_1-c)+\theta_1 c(a+bP_1)]- & +\theta_1 c(a+bP_1+G)-\theta_2 c(a+bP_2+G)] \\ \theta_2 G(P-P_2-c)+\theta_2 c(a+bP_2)\} & \\ y(1-y)(K_h\theta_2-K_L\theta_1) & (1-2y)[x(K_h\theta_2-K_L\theta_1)+ \\ & (1+K_L)\theta_1+P_1-(1+K_h)\theta_2-P_2] \end{bmatrix}$$

If the local equilibrium point satisfies the following two conditions at the same time, the equilibrium point of the replication dynamic equation is the evolutionary stability strategy, namely ess.

(1) $trJ=a_{11}+a_{22}<0$ ;

(2) $\det J=\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix}=a_{11}a_{22}-a_{12}a_{21}>0$。

Four purely strategic partial equilibrium points can be obtained from the above conditions. $a_{11},a_{12},a_{21},a_{22}$ The value is as shown in Table 2:

Table 2 local equilibrium point $a_{11},a_{12},a_{21},a_{22}$ Specific value

| Equilibrium point | $a_{11}$ | $a_{12}$ | $a_{21}$ | $a_{22}$ |
|---|---|---|---|---|
| (0,0) | $-\theta_2 G(P-P_2)+\theta_2 c(a+bP_2+G)$ | 0 | 0 | $(1+K_L)\theta_1+P_1-(1+K_h)\theta_2-P_2$ |
| (0,1) | $-\theta_1 G(P-P_1)+\theta_1 c(a+bP_1+G)$ | 0 | 0 | $-[(1+K_L)\theta_1+P_1-(1+K_h)\theta_2-P_2]$ |
| (1,0) | $\theta_2 G(P-P_2)-\theta_2 c(a+bP_2+G)$ | 0 | 0 | $\theta_1+P_1-\theta_2-P_2$ |
| (1,1) | $\theta_1 G(P-P_1)-\theta_1 c(a+bP_1+G)$ | 0 | 0 | $-[\theta_1+P_1-\theta_2-P_2]$ |

It can be seen from the calculation that the (x*, y*) point obviously does not conform to the trace condition described above, so it is not the evolutionary stability strategy point of the system, but as the saddle point (DetJ>0, TrJ=0).Therefore, it is only necessary to judge the stability of the other four points.

due to $0<y^*<1$ So there are: $\begin{cases}\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)>0\\ \theta_2 G(P-P_2-c)-\theta_2 c(a+bP_2)<0\end{cases}$,

Or $\begin{cases}\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)>0\\ \theta_2 G(P-P_2-c)-\theta_2 c(a+bP_2)>\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)\end{cases}$。

And $0<x^*<1$,so there are: $\theta_2-\theta_1+P_2-P_1<0$, and $(1+k_h)\theta_2+P_2-(1+k_l)\theta_1-P_1>0$,

From this, the matrix determinant and trace positive and negative of each point in different cases can be obtained. The specific stability analysis is shown in Table 3.

Table 3 Stability analysis

| Stable point | Situation 1 Det$J$ | Situation 1 $trJ$ | Situation 1 result | Situation 2 Det$J$ | Situation 2 $trJ$ | Situation 2 result |
|---|---|---|---|---|---|---|
| (0,0) | — | uncertain | Unstable | — | — | ESS |
| (0,1) | + | + | Unstable | + | + | Unstable |
| (1,0) | — | uncertain | Unstable | + | + | Unstable |
| (1,1) | + | — | ESS | + | — | ESS |

The following is analyzing the behavioral decisions of consumers and remanufacturing companies in different situations.

(1) When $\begin{cases}\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)>0\\ \theta_2 G(P-P_2-c)-\theta_2 c(a+bP_2)<0\end{cases}$,At that time, when the profit of the remanufacturing company using the O2O method is always less than the profit recovered by the traditional method, the steady state of the system is (1, 1). That is to say, at this time, the remanufacturing enterprises use the traditional methods for recycling, and the consumer groups have evolved into traditional consumers. This state is not an ideal state, so this case is not considered in the analysis below.

(2) When $\begin{cases}\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)>0\\ \theta_2 G(P-P_2-c)-\theta_2 c(a+bP_2)>\theta_1 c(a+bP_1)-\theta_1 G(P-P_1-c)\end{cases}$, When remanufacturing companies use the O2O method to recover from green consumers, the benefits from remanufacturing companies using the O2O method to recover from traditional consumers are higher; at the same time, consumers' participation in recycling is more effective. At this point, the system has two evolutionary stability strategy points: (1,1) and (0,0). That is: the choice strategy for remanufacturing companies and consumers is (remanufacturing companies use traditional methods to recycle, consumer groups are traditional consumers) or (remanufacturing companies use O2O to recycle, consumer groups are green consumers).

## 4. System evolution simulation

Based on the above analysis, it can be seen that the evolutionary game system composed of remanufacturing enterprises and consumers will eventually reach a state of evolutionary equilibrium, but the specific process of system evolution is not clear. Therefore, based on the above assumptions, this paper uses Matlab software to perform dynamic system simulation of this evolutionary game system. In order to clarify the evolution process of remanufacturing enterprises and consumer groups, the parameters are assigned as follows and the system is simulated based on literature and related research. $\theta_1=0.5,\theta_2=0.8,P_1=2,P_2=1,P=5,k_l=0.4,k_h=1.5,a=3,b=1,G=2,c=1$。

### 4.1 Analysis of the impact of initial strategy selection on evolutionary results

(1) $x$、$y$ Re-manufacturing companies use traditional methods to recover the initial proportions of traditional consumers in the consumer group, in order to further analyze the change in the proportion of recycling methods of remanufacturing enterprises in an initial state of the system and the changes in the proportion of two consumers in the consumer group. The effect of the results was simulated as follows: $x$、$y$ The initial ratio is 0.5, by changing $x$、y The ratio is used to analyze the ultimate evolutionary state of remanufacturing companies and consumers.

The proportion of the way in which remanufacturing companies recycle used electronic products depends to a large extent on the distribution of traditional and green consumers in the consumer group. Compared with remanufacturing companies, consumers' participation in recycling is very low, so the enthusiasm is not high, but the increase of green consumers in the consumer group will increase the awareness of the overall consumer group to participate in recycling, which in turn affects the amount of recycling. Therefore, considering the distribution ratio of traditional consumers and green consumers in the consumer system is of great significance to the way in which remanufacturing companies choose to recycle. It can be seen from Figure 1 that as the remanufacturing enterprise adopts the O2O method for recycling, the final evolutionary stability strategy of the remanufacturing enterprise is gradually shifted from the non-ideal state recovered by the traditional method to the utilization of O2O. The way the ideal direction machine for recycling is evolved. From the consumer point of view, when the proportion of traditional consumers in the consumer group is higher, that is, the consumer group's willingness to participate in recycling is low, the remanufacturing enterprise will eventually evolve to the state of recycling using the traditional method. Conversely, when the proportion of green consumers in the consumer group is high, the remanufacturing company will gradually evolve into the ideal direction of recycling using the O2O method.

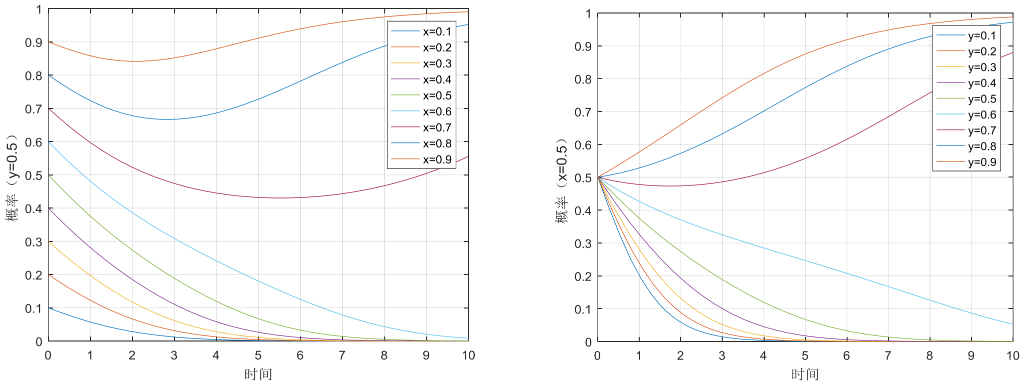


Figure 1 Producer evolution path diagram

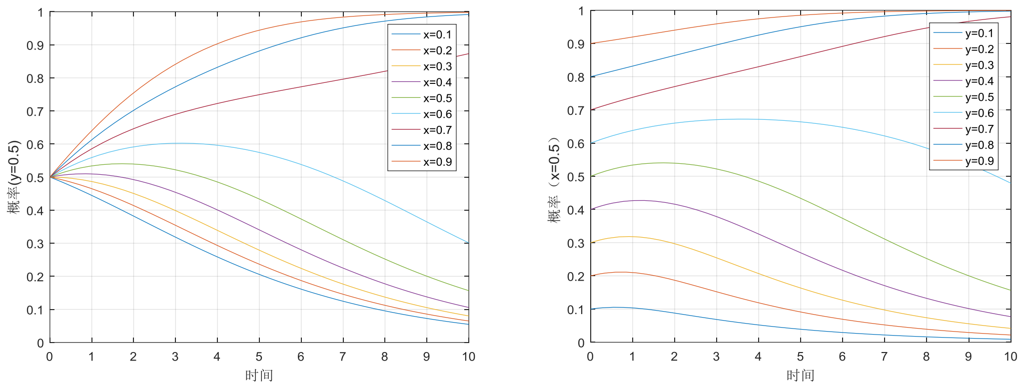


Figure 2 Consumer evolution path diagram

(2) From the consumer's point of view, consumers play a vital role in participating in recycling. Consumers' awareness of recycling will have a certain impact on the recycling volume of remanufacturing companies. Consumers will also seek to make the most effective decisions by learning from each other, thus changing their behavioral decisions. It can be seen from Figure 2 that when the proportion of initial selection of remanufacturing companies changes, the consumer groups will eventually present different selection strategies. In the initial state, when remanufacturing companies use a higher proportion of traditional methods for recycling because they cannot use O2O to form stable returns, the consumer group will gradually adopt an evolutionary strategy that is conducive to increasing its own utility, and ultimately to traditional consumption. The direction of the person evolves. As remanufacturing companies increase their confidence in O2O recycling, increase their investment, and increase the use of O2O recycling, traditional consumers will gradually change their own by changing their expectations of their earnings and behavioral learning to green consumers. Consumer awareness, and then gradually transform into the direction of green consumers,

green consumers will be the ultimate evolutionary stability strategy of the consumer group. In addition, starting from the consumer's own choice strategy, the awareness of green consumers participating in recycling is higher than that of traditional consumers. However, when the proportion of traditional consumers is high, the overall recycling awareness of the consumer groups is low. The consumer community will evolve towards a non-ideal steady state that tends to traditional consumers. As traditional consumers slowly increase their awareness of recycling, the proportion of green consumers increases, and the system will eventually evolve into the ideal state of green consumers for the consumer group.

(3) By substituting the above parameters into the model and simulating with Matlab, the evolution strategy phase diagram of the system shown in Fig. 3 can be obtained. It can be seen that the system will eventually evolve two stable game stable states (0,0), (1,1), corresponding to the ideal state (remanufacturing companies use O2O for recycling, consumer groups are green consumers) And non-ideal states (remanufacturing companies use traditional methods to recycle, and consumers in the consumer group are traditional consumers). It can also be seen from Figure 3 that due to the incomplete rationality of both sides of the game, in the initial state of the system game, remanufacturing enterprises and consumers do not adopt the optimal strategy, but over time, both parties to the system pass constantly adjust the strategy and ultimately form a stable behavioral decision.

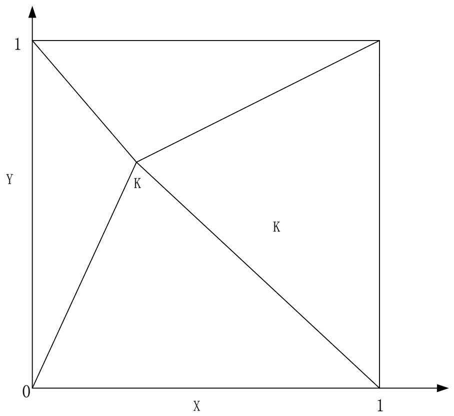


Figure 3 System evolution phase diagram

In addition, through the above analysis, we can see that the final state of the system evolution game depends on the initial state of each participant. As can be seen from Figure 3, k points are used as saddle points, and the phase map of the system evolution game is divided into different parts. When the initial state is at the lower left of the saddle point k, the final system will converge to (0.0); when the initial state of both sides of the game is at the upper right of the saddle point, the system will eventually converge to (1, 1). The movement of the saddle point can change the area of different parts, thus affecting the final convergence of the system. It is therefore possible to guide the evolution of the system to an ideal state by adjusting the parameters associated with the saddle point.

### 4.2 The impact of different logistics costs on the evolution of O2O recovery

For saddle point k, for remanufacturing companies, when using the logistics costs of a single transaction in the O2O recycling process $c$ From 1 to 0.9, while other parameters remain unchanged, the system evolution game phase diagram of Figure 4 can be obtained by simulation. At this point, it can be seen from the calculation that x* remains unchanged, and y* will move upward. It can be seen from Fig. 4 that the area of the lower left corner portion of the saddle point K increases, indicating that the probability of the system evolving to the (0, 0) state increases. That is, when remanufacturing companies reduce logistics costs, it is beneficial for remanufacturing companies to speed up the use of O2O for recycling. At the same time, it can be concluded from Figure 5 and Figure 6 that when reducing the logistics cost of O2O recycling by remanufacturing enterprises, no matter how high the recycling rate of remanufacturing enterprises using traditional methods, they will eventually evolve into O2O recycling, and consumers also will be more inclined to evolve into a green consumer.

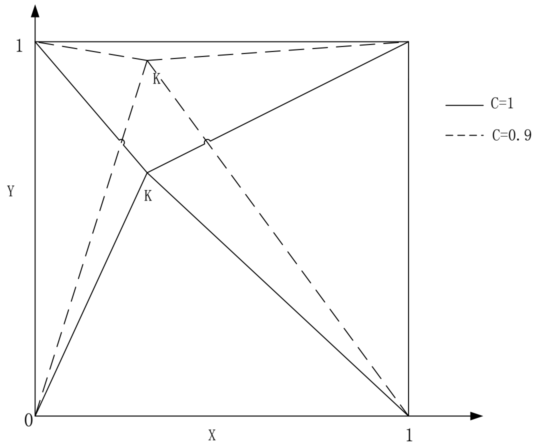


Figure 4 lowering $c$ Time evolution game phase diagram

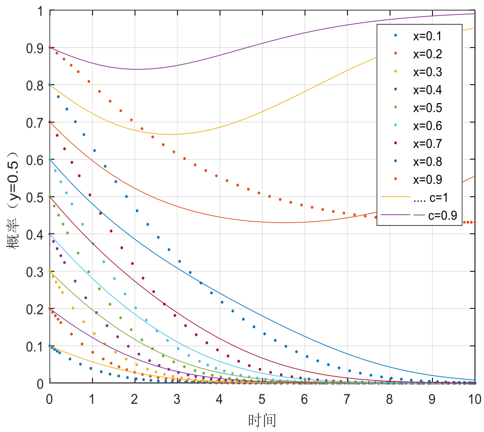


Figure 5 $c$ Impact on remanufacturing decisions

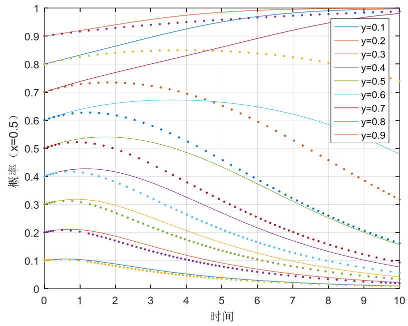


Figure 6 $c$ Impact on consumer decision making

### 4.3 The impact of changes in traditional consumers' willingness to recycle on evolutionary outcomes

As traditional consumers increase their willingness to participate in recycling through behavioral learning and awareness-raising, they actively participate in recycling and adjust parameters. $\theta_1$ From 0.5 to 0.6, at this time, $x^*$ Move horizontally to the left, $y^*$ Move Downward. It can be seen from Fig. 5 that the area of the upper right corner of the saddle point k becomes larger at this time, that is, the probability of the system evolving to the steady state (1, 1) increases, so that increasing the willingness of the traditional consumers to recycle will promote the system to a non-ideal state. Cover. This is because the traditional consumers' willingness to recycle is higher, the utility they receive is higher, and the recycling volume of remanufacturing companies is also increased. The remanufacturing company's revenue from traditional consumers is higher than the original. .However, after the traditional consumers' willingness to recycle is increased, the remanufactured enterprises use the traditional method to recover more revenue than the use of O2O recycling, so the probability of the system's evolution to (1,1) increases. It can also be seen from Fig. 8 and Fig. 9 that, under the same initial ratio, when the recycling consciousness of the traditional consumer is improved, the consumer decision is faster than the original convergence to 1. Remanufacturing companies will also accelerate the evolution of recycling using traditional methods.

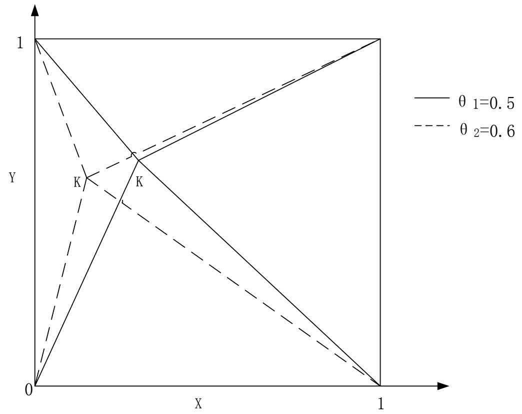


Figure 7 improves $\theta_1$ Time evolution game phase diagram

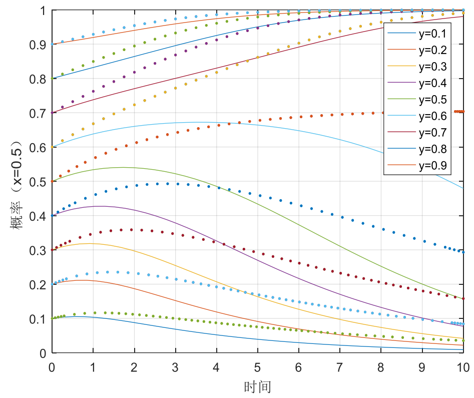


Figure 8 improves $\theta_1$ Impact on consumer decision making

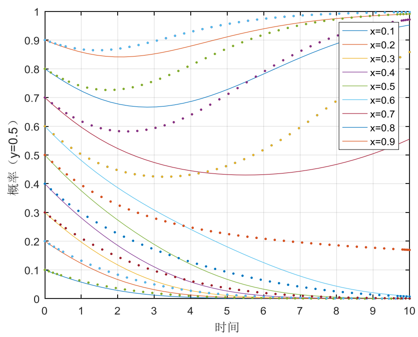


Figure 9 improves $\theta_1$ Impact on remanufacturing decisions

### 4.4 Impact of Green Consumers on the Evolutionary Results of Recycling Price Changes

From the perspective of improving the utility of consumers, when remanufacturing companies raise the recycling price for green consumers, $P_2$ When increasing from 1 to 1.5, $x^*$ Move horizontally to the right, $y^*$ Move vertically downwards. At this time, due to the greater utility of green consumers participating in recycling, the proportion of green consumers in the consumer group will increase, so remanufacturing companies are also more inclined to use the O2O method for recycling. It can also be seen from Fig. 6 that the area at the lower left of the saddle point k is increased from the original. That is to say, if the price of green consumers participating in the recycling is increased, the consumer group can be effectively stimulated to evolve into a green consumer, thereby facilitating the evolution of the system to an ideal stable state (0, 0).From Figure 9, after adding p2. Even if the initial proportion of traditional consumers reaches 80%, the consumer group will evolve toward the direction of green consumers. At the same time, it can be seen from Figure 10 that remanufacturing companies are more inclined to use the O2O method for recycling.

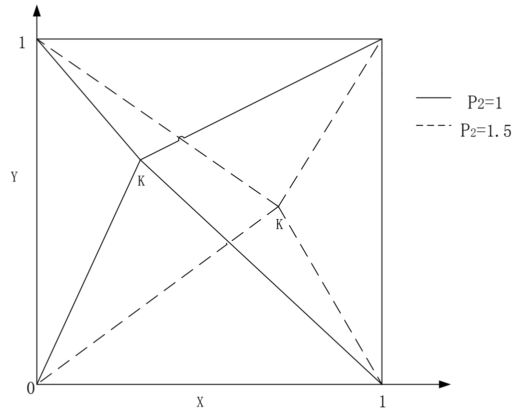


Figure 10 increases $P_2$ Time evolution game phase diagram

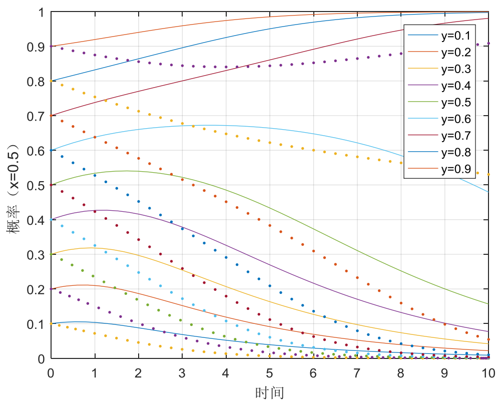


Figure 11 increase $P_2$ Impact on consumer decision making

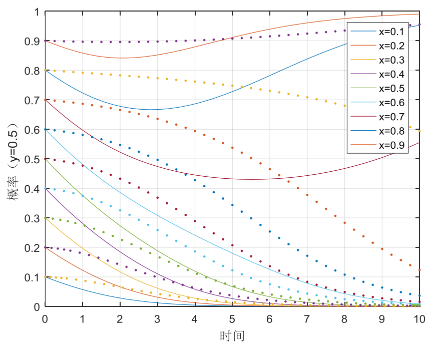


Figure 12 increases $P_2$ Impact on remanufacturing decisions

## 5. Conclusions and deficiencies

By using evolutionary game and Matlab simulation to analyze the stakeholders in the recycling of waste electronic products, the following conclusions are drawn: (1) It can be known from the evolution law of consumers and remanufacturing enterprises that the behavior choice of one party in the system The evolution strategy of the other side has a certain influence. Remanufacturing companies use traditional methods and O2O recycling methods to recycle used electronic products, but the initial ratio will affect the speed at which the system will eventually stabilize. The initial ratio of traditional consumers to green consumers in the consumer group also affects the evolution rate of the system. And consumers and remanufacturing companies will interact with each other. For example, if the remanufacturing company chooses to use the O2O method to recover a large proportion in the initial situation, the green consumer in the consumer group has a relatively high utility. So the traditional consumer learns through the behavior of the green consumer and finally chooses become a green consumer.(2) Changing parameters will have an impact on the evolution process of the system. Reducing the logistics costs of remanufacturing companies using O2O recycling and increasing the recycling price for green consumers will speed up the evolution of the system to the ideal state of (0,0). However, increasing the willingness of traditional consumers to recycle will increase the probability that the system will stabilize to (1,1).

This paper establishes an evolutionary game model for waste electronic products to be recycled by consumers and remanufacturing enterprises, and draws relevant conclusions through solving and analyzing the model, which can provide a certain reference for recycling of used electronic products. However, the article only considers the situation in which remanufacturing companies lead recycling and consumers participate in recycling. In future research, further consideration can be given to the introduction of model research in the context of the government's reward and punishment mechanism or subsidy mechanism.

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