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An Evolutionary Game Study of Recycling Strategies for Used Cell Phones Under Government Intervention

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ABSTRACT

Mobile phones are fast-changing and highly popularized, with high carbon emissions, and have both economic and environmental attributes. Increasing the amount of used cell phones recycled and recycling them effectively has become an urgent challenge to be solved. In order to explore the strategic choices of each participant involved in recycling, this paper constructs an evolutionary game model of local government, recycling enterprises and consumers, analyzes the stability of the strategic choices of each game subject, and further analyzes the stability of the equilibrium point in the tripartite game system using Jacobi matrix. Finally, simulation analysis is carried out to discuss the influence of key parameters on the evolution of the participants' behavior. The results of the study show that:(1) the implementation of government subsidies can incentivize enterprises to increase the rate of active recycling, but there is an upper limit to the subsidies, otherwise the government will take a non-regulatory strategy;(2) the probability of the government to achieve the strength of the penalty directly affects the strategic choice of recycling enterprises, when the penalty coefficient is less than 0.5,recycling enterprises for the government's penalties are not sensitive to continue to maintain the initial strategic choice;(3) recycling enterprises to increase the probability of the The probability of consumer subsidies can motivate consumers to participate in recycling, with the increase of subsidy incentives to increase the probability of active participation in the choice of consumers also increased, but the subsidy incentive can not exceed 12 this queer value, otherwise the enterprise will choose a negative recycling strategy;(4) consumers themselves on the user's privacy concerns are higher, recycling enterprises and consumers will be positive recycling and active participation in the direction of the evolution of the government can take a non-regulatory strategy. can adopt a non-regulatory strategy.

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KEYWORDS*: government intervention; used cell phone recycling; three-way evolutionary game*

1. INTRODUCTION

With the popularization of 5G network and the increasing demand for cell phone functions and appearance, cell phone manufacturers are innovating technology faster and faster, and the replacement cycle is shortening, and more and more cell phones are being phased out. According to a report by the NDRC, by the end of 2021, the number of cell phones in the domestic society had reached 1.856 billion, and it is expected that the total number of unused phones during the 14th Five-Year Plan period will reach 6 billion in total. However, the overall recovery rate of used cell phones in China is only about 4%, and less than 30% of the new idle cell phones enter the formal recycling field every year. A large number of used cell phones are collected by individual recyclers represented by mobile vendors, resold, refurbished, or crudely dismantled by small factories without being formally recycled and reutilized, which not only creates a huge waste of resources, but also buries the hidden risk of environmental pollution. This not only causes a huge waste of resources, but also buries the risk of environmental pollution. Over the years, China's relevant laws have implemented the extended production responsibility system and encouraged multi-channel recycling, but have not clearly defined the recycling channels and the distribution of economic responsibility, resulting in the existing recycling system is not perfect, and there is no standardized subsidy or reward and punishment standards, which weakens the recycling enthusiasm of enterprises in the reverse supply chain. At the same time, the existing recycling model brings the service level can not meet the expectations of consumers, the recycling price is low, the recycling experience is poor, the process of cell phone recycling is difficult to trace, out of privacy and security and other issues are the obstacles that lead to the failure to realize the effective recycling of used cell phones. In this context, how to safely and effectively recycle used cell phones deserves in-depth discussion.

The recycling of used cell phones is mostly studied under the category of waste electronic products, and this paper mainly combed the existing literature from three aspects: government intervention, recycling channels, and consumer participation in recycling.

The government's role in the recycling business includes legislation, incentives, penalties, subsidies, and taxes. Aksen et al.[1] explore the comparison of the optimality of legislative policies and develop and solve a two-tier planning model with a subsidy agreement signed between the government and recycling firms when the government acts as a leader and the firms act as a follower; Shao-Bu Bai[2] explores the closed-loop supply chain coordination mechanism based on the EPR system and develops a supply chain principal agent contract model based on which manufacturers can design optimal incentive contracts to maximize their expected profit utility; Wang Wenbin et al. [Error! Reference source not found.] explores the reward and punishment mechanism positively affects the recycling rate of waste products and the profits of supply chain members, and effectively promotes the enthusiasm of waste product recycling; meanwhile, Wang Xunkun et al. [Error! Reference source not found.] found that to a certain extent, the government reward and punishment mechanism can effectively alleviate the negative impact of manufacturers' fair concern behavior on the development of the recycling and remanufacturing industry; Gao Ming et al. [Error! Reference source not found.] concluded that the recycling price and the recycling rate of used products are positively correlated with the amount of government subsidies, which leads to an increase in the overall profit of the supply chain; Mitra et al. [Error! Reference source not found.] considered both manufacturers and remanufacturers, and compared government subsidies alone and at the same time, and found that subsidies at the same time can effectively promote the increase of profits of both; Mo Hongpin et al. [Error! Reference source not found.] concluded that the government can apply tax incentives to guide enterprises to increase the reuse of used products; Tian et al. [Error! Reference source not found.] studied the design strategy of government subsidy/tax policy under the EPR system based on the competitive situation of multiple manufacturers; Chang Xiangyun et al. [Error! Reference source not found.]

In order to study the impacts of different tax and subsidy policies on the environmental decisions of supply chain enterprises under the EPR constraints in a competitive supply chain system composed of a single producer and a single remanufacturer, and to provide a theoretical basis for the government's policy of "levy, reduction and subsidy".

In the recycling supply chain, the structure of the recycling channel and its selection are critical to the operational effectiveness of the entire supply chain. **Error! Reference source not found.** As early as 2004, Savaskan et al. [Error! Reference source not found.] modeled and analyzed the recycling logistics channel selection problem, compared the three recycling channel models of manufacturer's own recycling, retailer's recycling, and third party's recycling, and concluded that the retailer responsible for recycling is better than the manufacturer's own recycling and third party's recycling, and that the situation of retailer's recycling was improved through the coordination mechanism; Chuang et al. [Error! Reference source not found.] analyzed the choice of recycling channels for high-tech products and found that retailer recycling is the optimal channel when the recycling cost structure is similar; Li et al. [Error! Reference source not found.] discussed the advantages and disadvantages of manufacturers' recycling, retailers' recycling and third-party recyclers' recycling based on the competitive supply chain perspective, and obtained the optimal recycling channel structure; Li et al. [Error! Reference source not found.]

Some scholars have found that the dual-channel recycling model after introducing online recycling is significantly better than the single-channel recycling model in promoting the recycling of waste products and improving recycling efficiency; Lin J et al. [Error! Reference source not found.] analyze the impact of channel competition coefficient on supply chain pricing strategy based on dual-channel recycling; Chen et al. [Error! Reference source not found.] analyzed the impact of channel competition coefficient on supply chain pricing strategy based on dual-channel recycling; Chen et al. [Error! Reference source not found.] developed a quality-based price competition model for the

WEEE recycling market in a dual-channel environment including formal and informal recyclers, and examined the equilibrium purchase price and the effect of government subsidies of the two channels under different competition scenarios; ZhouWenhui[Error! Reference source not found.]et al. Constructed a two-period model in which the manufacturer is responsible for sales and two recyclers for recycling, and numerically demonstrated that the legislation improves environmental performance and reduces the total profit of both the manufacturer and the recycler; Liu Yuxin et al. [Error! Reference source not found.]analyzed four recycling models based on nonlinear demand functions, namely, manufacturers, retailers, third parties, and manufacturers selling products directly and responsible for recycling, to provide reference for enterprises to choose suitable recycling models; Yi Yuyin et al. [Error! Reference source not found.]In the case of demand uncertainty, the model under three different recycling channels is studied, and the effects of recycling cost and new recycling rate on retail pricing, recycling channel decision-making, supply chain system and its members' profit expectations are analyzed by numerical simulation; Liu et al. [Error! Reference source not found.]constructed a dual recycling channel model, where the retailer participates in the recycling behavior with the original manufacturer in addition to selling new and recycled products, showing that the supply chain benefits can be optimized when the original manufacturer and the retailer work together on recycling; Huang Shao hui et al. [Error! Reference source not found.]constructed four mixed recycling channels and selected the optimal recycling strategy based on maximizing the revenue of the manufacturer, the system as a whole, and maximizing the social benefits.

In terms of consumer participation in recycling, it is mainly considered from the perspective of consumer preference.

Jenni[Error! Reference source not found.]studied consumers' recycling awareness and recycling behavior based on two theoretical models, TPB and VBN, and found that consumers' awareness of recycling used cell phones is not low, but their recycling behavior is relatively low, which indicates that consumers are not motivated to recycle; Li Y et al. [Error! Reference source not found.]considered consumer preferences and found that consumer preferences and external factors such as government subsidies affect the supply chain under different government management mechanisms; Gao Juhong et al. [Error! Reference source not found.]investigated the differences in willingness to pay for new, remanufactured and used products between ordinary and green consumers, and the impact of changes in consumer preference on the supply chain; Cheng Fa-Xin et al. [Error! Reference source not found.]explored the impacts of subsidy amount per unit of remanufactured product, subsidy weight and consumers' green preference on product pricing and demand in a closed-loop supply chain; Zhou Weilang et al. [Error! Reference source not found.]Using game theory for manufacturer-led and retailer-led closed loop supply chain pricing modeling, we explored that both consumer recognition of remanufactured products and production capacity of remanufacturing firms bring positive benefits to all firms; Peng et al. [Error! Reference source not found.]Under the condition of consumers' low-carbon preference, the Stackelberg game model is used to study the production, price and carbon emission decisions of the supply chain; Gong Bengang et al. [Error! Reference source not found.]considering consumers' channel preference and low-carbon preference under the condition of capacity constraints, we study the decision-making and coordination problems among members of a dual-channel supply chain, and construct a dual-channel supply chain decision-making model using game theory; Wang et al. [Error! Reference source not found.]considering consumers' preference for low-carbon products, the decision-making and coordination problems of retailer-led low-carbon supply chain under altruistic preference are investigated; Li Luyuan[Error! Reference source not found.]by applying Stackelberg's game theory, the impacts of consumer preferences and recycling detection errors on the profitability of closed-loop supply chain members under different scenarios of single-channel and dual-channel are investigated and optimized.

Existing literature mostly uses general game theory to model the optimal decisions of firms in the recycling supply chain, and seldom considers the inclusion of consumer factors in the model for quantification.

Recycling of used cell phones involves more sensitive issues such as privacy protection than other electronic products, so it is necessary to include consumers in the game. In view of this, this paper proposes to consider the reward and punishment mechanism of the government, and incorporate the three game subjects of local government, recycling enterprises and consumers into a recycling system using the evolutionary game to carry out research. A three-party evolutionary game model is constructed, and by analyzing the dynamic changes of the three parties under different strategies, the government's appropriate rewards and punishments are explored to promote active recycling of recyclers, motivate consumers to actively participate, increase the amount of recycling of used cell phones, reduce the pressure on the environment, and realize the recycling of resources.

2. Model Assumptions and Construction

2.1. Description of the problem

As the main stakeholders in the used cell phone recycling supply chain, effective collaboration among local governments, recycling enterprises and consumers is the key to rationalizing and greening the used cell phone recycling management issue. However, at present, the recycling of used cell phones is still dominated by individual recyclers, which leads to insufficient recycling volume and low motivation of formal recycling enterprises. For consumers, because used cell phones are different from general electronic products, there are privacy leakage and other security risks, on the other hand, the most convenient way to dispose of used cell phones is to leave them at home, even if they participate in the recovery of cell phones through the formal recycling channels, the utility brought about by the recycling can not meet the psychological expectations of consumers, so how to incentivize consumers to participate in the recycling of the downstream of the reverse supply chain has become a problem that needs to be solved. The problem. Finally, the government, as the regulator of the used cell phone recycling market, bears the responsibility of managing the environment and safeguarding public rights and interests, and needs to regulate and constrain the recycling enterprises, encourage consumers to actively participate in the recycling process by means of policy formulation and publicity, reduce environmental pollution, and realize the recycling of resources.

In this paper, with the help of evolutionary game theory, the local government, recyclers and consumers are regarded as limited rational participants, the group of participants is used to replace the individual participants, and the percentage of individuals choosing different pure strategies in the group to the total number of individuals in the group is used to replace the mixed strategies[33]. Based on the perspective of synergistic evolution of stakeholders, we constructed a tripartite evolutionary game model of local government, recycling enterprises and consumers to study the behavioral strategies and evolutionary trends of the local government, recyclers and consumers in the recycling market of used cell phones, and further analyzed the influence of relevant parameters on the behavioral strategies of the participants in the recycling of used cell phones, and then analyzed the evolutionary status of the manufacturers and consumers under the different regulatory intensities of the government through numerical simulation, and summarized the evolutionary status of the manufacturers and consumers under the different regulatory intensities of the government. Then, we analyze the evolution state of manufacturers and consumers under different regulatory intensities of the government through numerical simulation, and summarize the evolution results under different situations, so as to provide theoretical basis and decision-making suggestions for the healthy development of the used cell phone recycling industry.

2.2. Model assumptions

Hypothesis 1: The main participants in the supply chain of used cell phone recycling are: local government, recycling enterprises and consumers. In the process of recycling used cell phones, the three parties do not know the strategies of the other two parties beforehand, and they are all limited rationality, with incomplete asymmetry in the information they hold.

Hypothesis 2: The strategy choice space of the recycling firm is S_e= (positive recycling, negative recycling), the probability of choosing the "positive recycling" strategy is x, the probability of choosing the "negative recycling" strategy is $1-x$; The consumer's strategy choice space is $S_c =$ (active participation, passive participation), the probability of choosing "active participation" strategy is$y$,the probability of choosing the "negative participation" strategy is$1-y$; The government's strategy choice space is S_g = (regulate, don't regulate), the probability of choosing the "regulate" strategy is z, and the probability that it chooses the strategy of "no regulation" is $1-z.x,y,z\in[0,1]$.

Hypothesis 3: When the local government chooses "no supervision", it does not intervene in the waste mobile phone recycling market, but needs to pay corresponding environmental governance costs $P_iE(i=1,2,3)$, P_i represents the degree coefficient of environmental pollution under different strategy combinations ($P_1<P_2<P_3$); When choosing "supervision" : the enterprise actively carries out the recycling work to provide financial subsidies I, the subsidy intensity is α, then the subsidy amount is αI, and the enterprise is supervised in the negative recycling, and the enterprise is fined F for the violation in the recycling process, the penalty intensity is β, and the fine βF is charged. Among them, the regulatory cost of the government is Q, and its effective regulatory behavior will bring positive

social benefits G_1 (including reputation, environmental improvement, etc.).

Hypothesis 4: When the recycling enterprise chooses "negative recycling", it will continue to maintain the original recycling channel and operation mode, and the income is π_1; When recycling enterprises choose "active recycling", they will actively expand recycling channels and change their business mode, including absorbing idle individual recyclers and building recycling platforms, with a return of π_2. At the same time, consumers who actively participate in mobile phone recycling are given a certain subsidy incentive, which is R.

Hypothesis 5: When consumers choose "passive participation", they will choose idle mobile phones or resell mobile phones through informal recycling channels, earning π_3, but it will also increase the idleness of used mobile phones, or the possibility of flowing into informal channels for secondary refurbishment, resale, and illegal dismantling, resulting in environmental pollution, disorder of recycling market order, and resulting social losses of S; When consumers choose "active participation" : they will seek formal recycling enterprises to participate in mobile phone recycling, and the income is π_4. In addition, when consumers passively recycle, they basically choose to idle waste mobile phones, and the income brought by this time is usually lower than that brought by recycling enterprises, that is, $\pi_3 < \pi_4$.

Hypothesis 6: Unlike general used electronic products, privacy security is an important factor for consumers to consider whether to participate in recycling, so recycling companies will introduce privacy shredding service technology to safeguard users' rights and interests when actively recycling, at a cost of C_0. The cost is This will bring additional utility to consumers who actively participate in recycling λU, Theλrepresents users' privacy concern and will bring corresponding word-of-mouth effect to the enterprise G_2.

The parameters and meanings of the model in this paper are shown in Table 2-1.

Table 2-1 Variable Parameters and Meaning

notation	hidden meaning	notation	hidden meaning
$P_i(i=1,2,3)$	Coefficient of environmental pollution level	λ	User privacy concern factor
E	Costs of environmental governance in the absence of government regulation	U	Consumers' Utility from Businesses Providing Privacy Service Assurance
α	Government's financial subsidy efforts	G_1	Social benefits of effective government regulation
β	Penalization by the Government	G_2	Word-of-mouth effect from recycling companies offering privacy protection services to consumers
I	Government financial subsidies to recycling companies	C_0	Costs incurred by recyclers in introducing privacy shredding service technology
F	Fines imposed by the Government for non-compliance by recycling enterprises in the recycling process	π_1	Gross proceeds in case of negative recycling by recycling firms
Q	Regulatory costs to the Government	π_2	Gross proceeds when recycling firms actively recycle
R	Subsidized incentives given by recycling companies to consumers to actively participate in cell phone recycling	π_3	Benefits derived from negative consumer participation in cell phone recycling
S	Social losses incurred by consumers in negative recycling	π_4	Benefits to consumers from active participation in cell phone recycling

2.3. Modeling

Based on the above assumptions, this paper constructs a mixed-strategy game matrix for local governments, recycling enterprises, and consumers, as shown in Table 2-2:

Table 2-2 Mixed game matrix of local government, recycling firms and consumers

strategic choice	consumers	local government	
		supervisory(z)	unregulated$(1-z)$

recycling company	Active recycling (x)	participate actively(y)	$\pi_2+\alpha I+G_2-R-C_0$, $\pi_4+R+\lambda U$, $G_1-Q-\alpha I$	$\pi_2+G_2-R-C_0$, $\pi_4+R+\lambda U$, 0
		Negative participation $(1-y)$	$\pi_2+\alpha I$, π_3, $-Q-S$	π_2, π_3, $-P_1E-S$
	Negative recycling $(1-x)$	participate actively(y)	$\pi_1-\beta F$, π_4, $\beta F-Q$	π_1, π_4, $-P_2E$
		Negative participation $(1-y)$	$\pi_1-\beta F$, π_3, $\beta F-Q-S$	π_1, π_3, $-P_3E-S$

3. Model analysis

3.1. Strategic stability analysis of recycling companies

Recycling firms choose the "active recycling" strategy, the "passive recycling" strategy, and their average expected return is

$$E_{11}=yz(\pi_2+\alpha I+G_2-R-C_0)+y(1-z)(\pi_2+G_2-R-C_0)+z(1-y)(\pi_2+\alpha I)+(1-y)(1-z)\pi_2$$

$$E_{12}=yz(\pi_1-\beta F)+y(1-z)\pi_1+z(1-y)(\pi_1-\beta F)+(1-y)(1-z)\pi_1$$

$$\overline{E_1}=xE_{11}+(1-x)E_{12}=xy(G_2-R-C_0)+xz(\beta F+\alpha I)+x(\pi_2-\pi_1)-z\beta F+\pi_1$$

Then the dynamic equation of replication under the aggressive recycling strategy of recycling firms is:

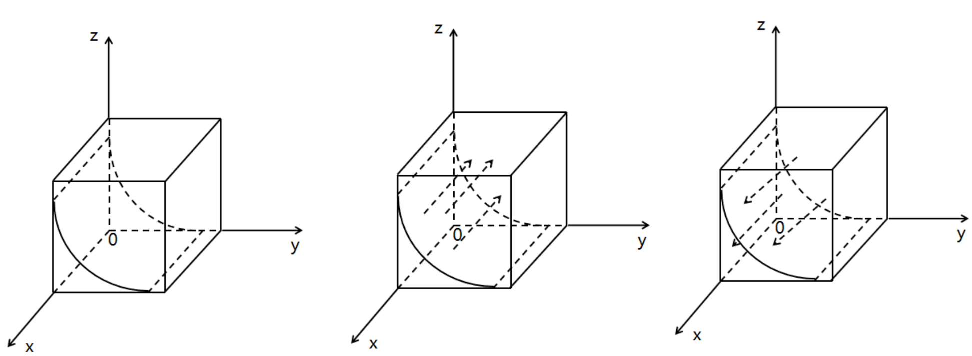
$$F(x)=\frac{dx}{dt}=x(E_{11}-\overline{E_1})=x(1-x)[y(G_2-R-C_0)+z(\beta F+\alpha I)+\pi_2-\pi_1]$$

According to the stability theorem for differential equations, when $F(x^*)=0$ the $\frac{dF(x^*)}{dx}<0$. x^* is the evolutionary stabilization strategy of the recycling firm. Let $F(x)$ for the x solve the partial derivation, we can obtain:

$$\frac{dF(x)}{dx}=(1-2x)[y(G_2-R-C_0)+z(\beta F+\alpha I)+\pi_2-\pi_1]$$

1. When $y=y_0=\frac{-z(\beta F+\alpha I)-\pi_2+\pi_1}{G_2-R-C_0}$, $F(x)\equiv 0$ and $F'(x)\equiv 0$, at this time x takes any value is a steady state, i. e., all recycling firm strategies are evolutionarily stable.
2. When$y\neq y_0=\frac{-z(\beta F+\alpha I)-\pi_2+\pi_1}{G_2-R-C_0}$, if $0<y<y_0$, $\frac{dF(x)}{dx_{x=0}}<0$ and $\frac{dF(x)}{dx_{x=1}}>0$.

In this case, $x=0$ is the evolutionary stabilization strategy of the recycling firm; if $y_0<y<1$, $\frac{dF(x)}{dx_{x=0}}>0$ and $\frac{dF(x)}{dx_{x=1}}<0$, at this point in time, $x=1$is the evolutionary stabilization strategy of the recycling firm (shown in Figure 3-1).



$y=y_0$ $0<y<y_0$ $y_0<y<1$

Figure 3-1 Dynamic Evolution of the Recycling Enterprise

3.2. Analysis of Consumers' Strategic Stability

Consumers chose the "active participation" strategy, the "passive participation" strategy and their average expected returns were

$$E_{21} = xz(\pi_4 + R + \lambda U) + x(1-z)(\pi_4 + R + \lambda U) + z(1-x)\pi_4 + (1-x)(1-z)\pi_4$$

$$E_{22} = xz\pi_3 + x(1-z)\pi_3 + z(1-x)\pi_3 + (1-x)(1-z)\pi_3$$

$$\overline{E_2} = yE_{21} + (1-y)E_{22} = y(\pi_4 - \pi_3) + xy(R + \lambda U) + \pi_3$$

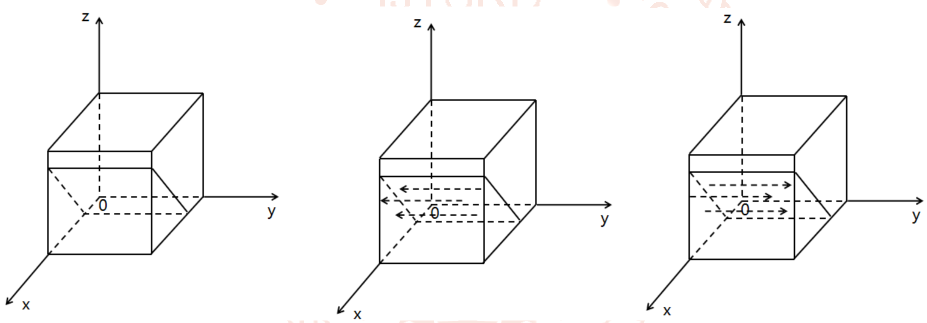
Then the equation of replication dynamics under active consumer participation strategy is:

$$F(y) = \frac{dy}{dt} = y(E_{21} - \overline{E_2}) = y(1-y)[x(R + \lambda U) + \pi_4 - \pi_3]$$

Similarly, when $F(y^*) = 0$ the $\frac{dF(y^*)}{dy} < 0$, y^* is the consumer's evolutionary stabilization strategy. Let $F(y)$ for the y solve for the partial derivation, we can obtain: $\frac{dF(y)}{dt} = (1-2y)[x(R + \lambda U) + \pi_4 - \pi_3]$

1. When $x = x_0 = \frac{\pi_3 - \pi_4}{R + \lambda U}$, $F(y) \equiv 0$ and $F'(y) \equiv 0$, at this time y takes any value is a steady state, i. e., all consumer strategies are evolutionarily stable.
2. When $x \neq x_0 = \frac{\pi_3 - \pi_4}{R + \lambda U}$, if $0 < x < x_0$, the $\frac{dF(y)}{dy_{y=0}} < 0$ and $\frac{dF(y)}{dy_{y=1}} > 0$, the

In this case, $y = 0$ is the consumer's evolutionary stabilization strategy; if $x_0 < x < 1$, $\frac{dF(y)}{dy_{y=0}} > 0$ and $\frac{dF(y)}{dy_{y=1}} < 0$, at this point in time, $y = 1$ is the consumer's evolutionary stabilization strategy (shown in Figure 3-2).



$x = x_0$ $0 < x < x$ $x_0 < x < 1$

Figure 3-2 Dynamic Evolution of the Consumer

3.3. Strategic stability analysis of local governments

Local governments choose the "regulate" strategy, the "don't regulate" strategy, and their average expected returns, respectively, are

$$E_{31} = xy(G_1 - Q - \alpha I) + x(1-y)(-Q - S) + y(1-x)(\beta F - Q) + (1-x)(1-y)(\beta F - Q - S)$$

$$E_{32} = x(1-y)(-P_1E - S) - y(1-x)P_2E + (1-x)(1-y)(-P_3E - S)$$

$$\overline{E_3} = zE_{31} + (1-z)E_{32} = z[xy(G_1 - \alpha I) - x\beta F + ys + \beta F - Q - S] + (1-z)[-x(1-y)(P_1E + S) - (1-x)(1-y)(P_1E + S) - y(1-x)P_2E]$$

Then the equation for the replication dynamics under the government regulatory strategy is:

$$F(z) = \frac{dz}{dt} = z(E_{31} - \overline{E_3}) = z(1-z)[xy(G_1 - \alpha I - P_1E - P_2E + P_3E) + x(P_1E - P_3E - \beta F) + y(P_2E - P_3E) + P_3E + \beta F - Q]$$

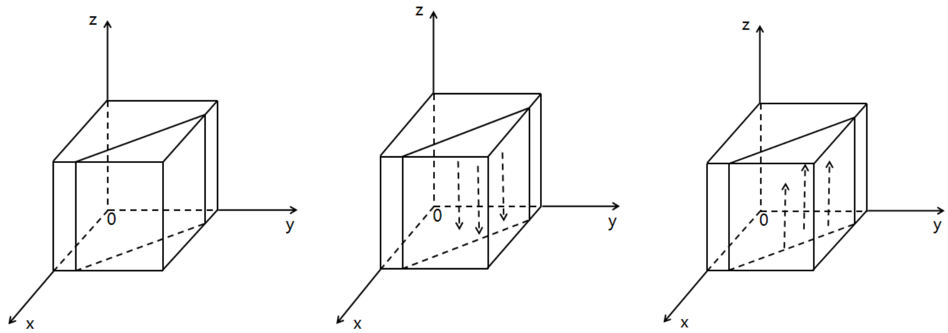
Similarly, when $F(z^*)=0$, the $\frac{dF(z^*)}{dz}<0$, z^* is the evolutionary stabilization strategy of the local government. Let $F(z)$ for the z solve the partial derivation, we can obtain:

$$\frac{dF(z)}{dz}=(1-2z)[xy(G_1-\alpha I-P_1E-P_2E+P_3E)+x(P_1E-P_3E-\beta F)+y(P_2E-P_3E)+P_3E+\beta F-Q]$$

(1) When $x=x_0=\frac{-y(P_2E-P_3E)-P_3E-\beta F+Q}{y(G_1-\alpha I-P_1E-P_2E+P_3E)+P_1E-P_3E-\beta F}$, $F(z)\equiv 0$ and $F'(z)\equiv 0$, at this point z takes any value is a steady state, i. e., all local government strategies are evolutionarily stable.

(2) When $x\neq x_0=\frac{-y(P_2E-P_3E)-P_3E-\beta F+Q}{y(G_1-\alpha I-P_1E-P_2E+P_3E)+P_1E-P_3E-\beta F}$, if $0<x<x_0$, $\frac{dF(z)}{dz_{z=0}}<0$ and $\frac{dF(z)}{dz_{z=1}}>0$, $z=0$ is the evolutionary stabilization strategy of the local government;

if $x_0<x<1$, $\frac{dF(z)}{dz_{z=0}}>0$, and $\frac{dF(z)}{dz_{z=1}}<0$, at this time $z=1$ is the local government's evolutionary stabilization strategy (shown in Figure 3-3).



$x=x_0$ $0<x<x_0$ $x_0<x<1$

Figure 3-3 Dynamic Evolution of Government

3.4. Stability analysis of the equilibrium point of a tripartite evolutionary game system

The three-dimensional dynamical system of used cell phone recycling is obtained by replicating the dynamic equations from local government, recycling enterprises and consumers as follows:

$$\begin{cases} F(x)=\frac{dx}{dt}=x(E_{11}-\overline{E_1})=x(1-x)[y(G_2-R-C_0)+z(\beta F+\alpha I)+\pi_2-\pi_1] \\ F(y)=\frac{dy}{dt}=y(E_{21}-\overline{E_2})=y(1-y)[x(R+\lambda U)+\pi_4-\pi_3] \\ F(z)=\frac{dz}{dt}=z(E_{31}-\overline{E_3})=z(1-z)[xy(G_1-\alpha I-P_1E-P_2E+P_3E)+ \\ x(P_1E-P_3E-\beta F)+y(P_2E-P_3E)+P_3E+\beta F-Q] \end{cases}$$

The following eight local equilibria are solved by making $F(x)=F(y)=F(z)=0$, solve for the following eight local equilibria: (0, 0, 0)、(0, 0, 1)、(0, 1, 0)、(0, 1, 1)、(1, 0, 0)、(1, 0, 1)、(1, 1, 0)、(1, 1, 1)。

The evolutionary stabilization strategy for a system of differential equations can be derived from the local stability analysis of the Jacobi matrix of this system. The Jacobi matrix of this system can be obtained from the replicated dynamic equations:

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

$$\begin{cases} j_{11} = (1-2x)[y(G_2 - R - C_0) + z(\alpha I + \beta F) + \pi_2 - \pi_1] \\ j_{12} = x(1-x)(G_2 - R - C_0) \\ j_{13} = x(1-x)(\alpha I + \beta F) \\ j_{21} = y(1-y)(\lambda U + R) \\ j_{22} = (1-2y)[x(\lambda + R) + \pi_4 - \pi_3] \\ j_{23} = 0 \\ j_{31} = z(1-z)[y(G_1 + P_3E - P_2E - P_1E - \alpha I) - \beta F + P_1E - P_3E] \\ j_{32} = z(1-z)[x(G_1 - \alpha I - P_1E - P_2E + P_3E) - P_3E + P_2E] \\ j_{33} = (1-2z)[xy(G_1 - \alpha I - P_1E - P_2E + P_3E) + x(-\beta F - P_3E + P_1E) + y(P_2E - P_3E) + \beta F \\ \quad - Q + P_3E] \end{cases}$$

Substituting each of the eight equilibrium points into the Jacobi matrix, the eigenvalues of the Jacobi matrix corresponding to the equilibrium points can be obtained separately, using the $Lyapunov$ The first law: all eigenvalues of the Jacobi matrix have a negative real part, the equilibrium point is an asymptotically stable point; at least one of the eigenvalues of the Jacobi matrix has a positive real part, the equilibrium point is an unstable point; all eigenvalues of the Jacobi matrix have a negative real part except the eigenvalue with a real part of zero, the equilibrium point is in a critical state, and the stability can't be determined by the sign of the eigenvalue. Analyze whether each equilibrium point is a systemESS, and determine the formation ESS conditions of the system (as shown in Table 3-1).

Table 3-1 System equilibrium points and their eigenvalues

balance point	eigenvalue (math.)λ_1	eigenvalue (math.)λ_2	eigenvalue (math.)λ_3	Progressive stability
(0, 0, 0)	$\pi_2 - \pi_1$	$\pi_4 - \pi_3$	$\beta F + P_3E - Q$	point of instability (math.)
(0, 0, 1)	$\beta F + \alpha I + \pi_2 - \pi_1$	$\pi_4 - \pi_3$	$Q - \beta F - P_3E$	point of instability (math.)
(0, 1, 0)	$G_2 - C_0 - R - \pi_1 + \pi_2$	$\pi_3 - \pi_4$	$\beta F + P_2E - Q$	Condition (1)
(0, 1, 1)	$\beta F + \alpha I + G_2 - C_0 - R + \pi_2 - \pi_1$	$\pi_3 - \pi_4$	$Q - \beta F - P_2E$	Conditions (2)
(1, 0, 0)	$\pi_1 - \pi_2$	$\lambda U + R + \pi_4 - \pi_3$	$P_1E - Q$	point of instability (math.)
(1, 0, 1)	$-\beta F - \alpha I + \pi_1 - \pi_2$	$\lambda U + R + \pi_4 - \pi_3$	$Q - P_1E$	point of instability (math.)
(1, 1, 0)	$R + C_0 - G_2 + \pi_1 - \pi_2$	$-R - \lambda U + \pi_3 - \pi_4$	$G_1 - Q - \alpha I$	Conditions (3)
(1, 1, 1)	$R + C_0 - G_2 - \beta F - \alpha I + \pi_1 - \pi_2$	$-R - \lambda U + \pi_3 - \pi_4$	$\alpha I + Q - G_1$	Conditions (4)

Table 3-2 Equilibrium point stability conditions for three-dimensional dynamical systems

balance point	Stability conditions	serial number
(0, 1, 0)	$G_2 - C_0 - R - \pi_1 + \pi_2 < 0$. ; $\beta F + P_2E - Q < 0$	(1)
(0, 1, 1)	$\beta F + \alpha I + G_2 - C_0 - R + \pi_2 - \pi_1 < 0$. ; $Q - \beta F - P_2E < 0$	(2)
(1, 1, 0)	$R + C_0 - G_2 + \pi_1 - \pi_2 < 0$. ; $G_1 - Q - \alpha I < 0$	(3)
(1, 1, 1)	$R + C_0 - G_2 - \beta F + \pi_1 - \pi_2 < 0$. ; $\alpha I + Q - G_1 < 0$	(4)

4. Simulation Analysis

According to each equilibrium point as the founding condition of the evolutionary stabilization strategy, using the$Matlab$Numerical simulations are performed to more intuitively reflect the tripartite evolutionary paths under different scenarios.

A. Scenario 1

When $G_2 - C_0 - R - \pi_1 + \pi_2 < 0$ and $\beta F + P_2E - Q < 0$, then (0, 1, 0) is an evolutionary stable strategy, i. e., the government does not regulate, recycling enterprises recycle negatively, and consumers actively participate in the recycling of used cell phones. In this process, the administrative fine charged by the government on recycling enterprises when they violate the law is smaller than the cost of the government's supervision on the whole process when recycling enterprises recycle negatively, while the cost paid by recycling enterprises when they choose to recycle actively is higher than the benefit they can obtain. Therefore, the government prefers the no-regulation strategy, and the recycling firm prefers the negative recycling strategy of keeping the status quo ante. Set the parameters that satisfy Case 1: $\pi_1 = 35$、$\pi_2 = 40$、$\pi_3 = 5$、$\pi_4 = 10$、$E = 15$、$U = 5$、$G_1 = 80$、$G_2 = 30$、$I = 60$、$C_0 = 25$、$F = 70$、$Q = 100$、$S = 20$、$P_1 = 0.2$、$P_2 = 0.5$、$P_3 = 0.8$、$\lambda = 0.6$、$\alpha = 0.7$、$\beta = 0.5$.

The evolutionary path (shown in Figure 4-1) shows that: the probability of the government adopting a non-regulation strategy and the recycling enterprise adopting a negative recycling strategy expands over time, the proportion of consumers actively participating in the recycling strategy increases over time, and the used cell phone recycling system eventually evolves to the equilibrium point (0, 1, 0).

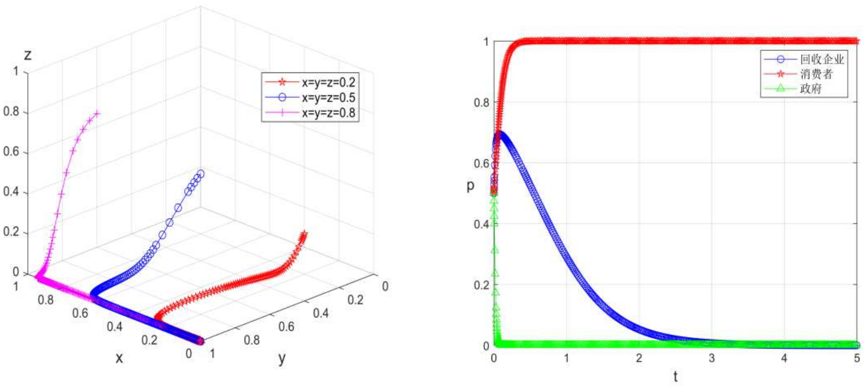


Figure 4-1 Three-party Evolutionary Path in Scenario 1

B. Scenario 2

When $\beta F + \alpha I + G_2 - C_0 - R + \pi_2 - \pi_1 < 0$ and $Q - \beta F - P_2 E < 0$, at this time (0, 1, 1) is an evolutionary stable strategy, i. e., the government regulates, recycling enterprises recycle negatively, and consumers actively participate in the recycling of used cell phones. The extra cost paid by recycling enterprises to incentivize consumers to participate in recycling is higher than the extra benefit, while the benefit brought by the government due to regulation is higher than the cost it pays for environmental pollution control, etc. Therefore, the government tends to regulate the recycling market, and the recycling enterprises maintain a wait-and-see status.

Setting up parameters that satisfy Case 2:

$\pi_1 = 75$、$\pi_2 = 20$、$\pi_3 = 5$、$\pi_4 = 10$、$E = 70$、$U = 5$、$G_1 = 80$、$G_2 = 15$、$I = 60$、$C_0 = 18$、$F = 65$、$Q = 80$、$R = 25$、$S = 20$、$P_1 = 0.7$、$P_2 = 0.8$、$P_3 = 0.9$、$\lambda = 0.6$、$\alpha = 0.7$、$\beta = 0.5$. The evolution path (shown in Figure 4-2) shows that the probability of the government adopting a regulatory strategy expands over time, the proportion of recycling enterprises adopting a negative recycling strategy decreases over time, the proportion of consumers actively participating in the recycling strategy increases over time, and the recycling system for used cell phones eventually evolves to the equilibrium point (0, 1, 1).

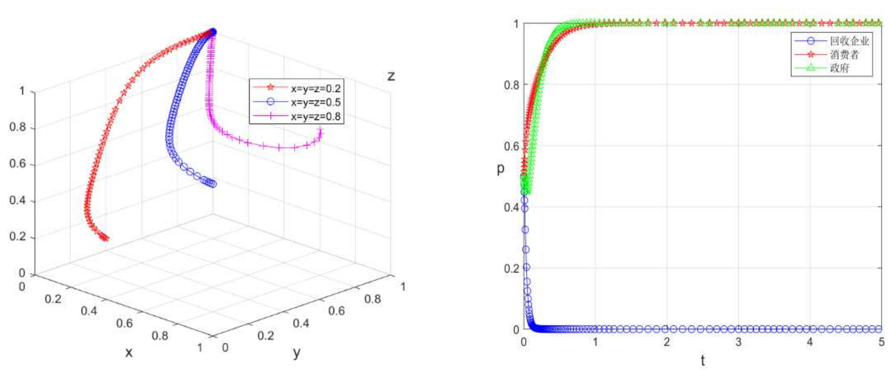


Figure 4-2 Three-party Evolutionary Path in Scenario 2

C. Scenario 3

When $R + C_0 - G_2 + \pi_1 - \pi_2 < 0$ and $G_1 - Q - \alpha I < 0$, at this time (1, 1, 0) is an evolutionary stable strategy, i. e., the government does not regulate, recycling enterprises actively recycle, and consumers actively participate in the recycling of used cell phones. As the recycling enterprises give consumers subsidy incentives to promote the recycling of cell phones and provide services such as privacy shredding technology, the benefits are higher than the costs they pay, and consumers also get greater benefits from participating in the recycling, and at this time, the government's cost of regulation is lower than the benefits, so the recycling enterprises and consumers are inclined to actively recycle, and the government chooses not to regulate. Set the parameters that satisfy scenario 3:

$\pi_1 = 35$、$\pi_2 = 45$、$\pi_3 = 5$、$\pi_4 = 10$、$E = 15$、$U = 5$、$G_1 = 80$、$G_2 = 30$、$I = 60$、$C_0 = 25$、$F = 70$、$Q = 100$、$R = 12$、$S = 20$、$P_1 = 0.2$、$P_2 = 0.5$、$P_3 = 08$、$\lambda = 0.6$、$\alpha = 0.7$、$\beta = 0.5$The evolution path (shown in Figure 4-3) shows that the probability of the government adopting a non-regulation strategy expands over time, the proportion of recycling enterprises adopting an active recycling strategy, and the probability of consumers actively participating in the recycling strategy increases over time, and the used cell phone recycling system eventually evolves to the equilibrium point (1, 1, 0).

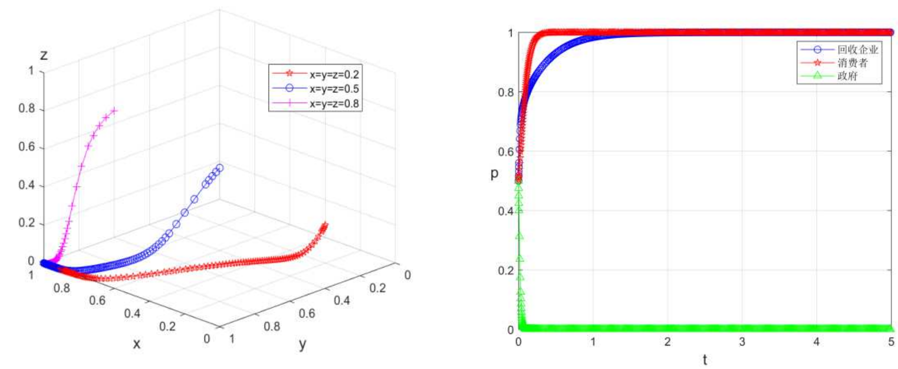


Figure 4-3 Three-Party Evolutionary Path in Scenario 3

D. Scenario 4

When $R + C_0 - G_2 - \beta F + \pi_1 - \pi_2 < 0$ and $\alpha I + Q - G_1 < 0$, then (1, 1, 1) is an evolutionary stable strategy, i. e., the government regulates, recycling enterprises actively recycle, and consumers actively participate in the recycling of used cell phones. The fine charged by the government for the regulation of enterprises in the negative recycling process motivates enterprises to actively recycle to make up for the loss, and the incentives and services provided by enterprises to consumers increase consumers' motivation to recycle, at this time, the government obtains the social benefits, and the recycling enterprises also obtain the additional benefits brought by word-of-mouth effect. Set the parameters to satisfy scenario 4:

$\pi_1 = 40$、$\pi_2 = 46$、$\pi_3 = 8$、$\pi_4 = 10$、$E = 15$、$U = 5$、$G_1 = 90$、$G_2 = 22$、$I = 60$、$C_0 = 15$、$F = 50$、$Q = 70$、$R = 12$、$S = 20$、$P_1 = 0.2$、$P_2 = 0.5$、$P_3 = 0.8$、$\lambda = 0.1$、$\alpha = 0.1$、$\beta = 0.1$.The evolutionary path (shown in Figure 4-4) shows that the proportion of the government adopting a regulatory strategy, recycling companies adopting an active recycling strategy, and consumers actively participating in the recycling strategy all expand over time, and the used cell phone recycling system eventually evolves to the equilibrium point (1, 1, 1).

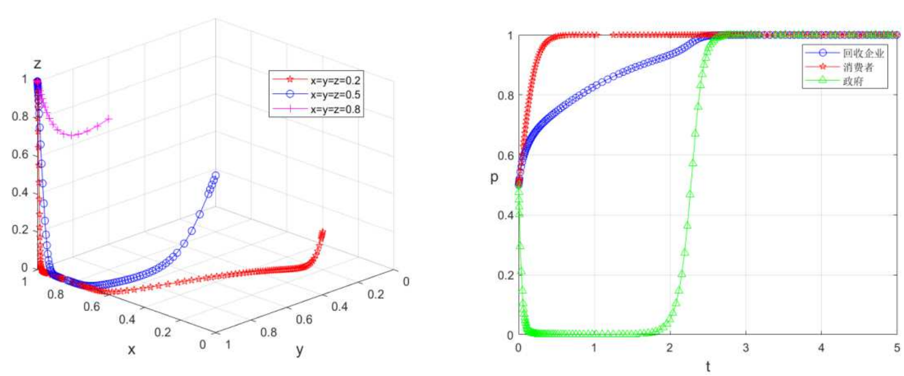


Figure 4-4 Three-Party Evolutionary Path in Scenario 4

4.1. Impact of government subsidy intensity α on evolutionary paths and evolutionary outcomes

In order to verify the correctness of the model and reflect the evolution paths of different participants more intuitively, and to analyze the factors affecting the strategy choices of each participant, the dynamic evolution process of local governments, recycling enterprises and consumers in different initial strategy choice probabilities is simulated through$Matlab$, and the neutral state of the initial strategy choice probability of the three parties, $x_0 = y_0 = z_0 = 0.5$, is used as the starting point of evolution, and the influence effects of the governmental department's subsidy strength, the punishment strength, the recycling enterprise's subsidy incentive, the additional service cost and the user privacy concern are discussed in focus. incentives, additional service costs, and user privacy concerns are discussed. On the basis of the parameter settings in Case 4, the government subsidy strength is adjusted, andα is taken as 0. 2, 0. 5 and 0. 8, respectively, to explore the impact of government subsidy incentives on the three-party evolution strategies, and the simulation results are shown in Figures 4-5 and 4-6.

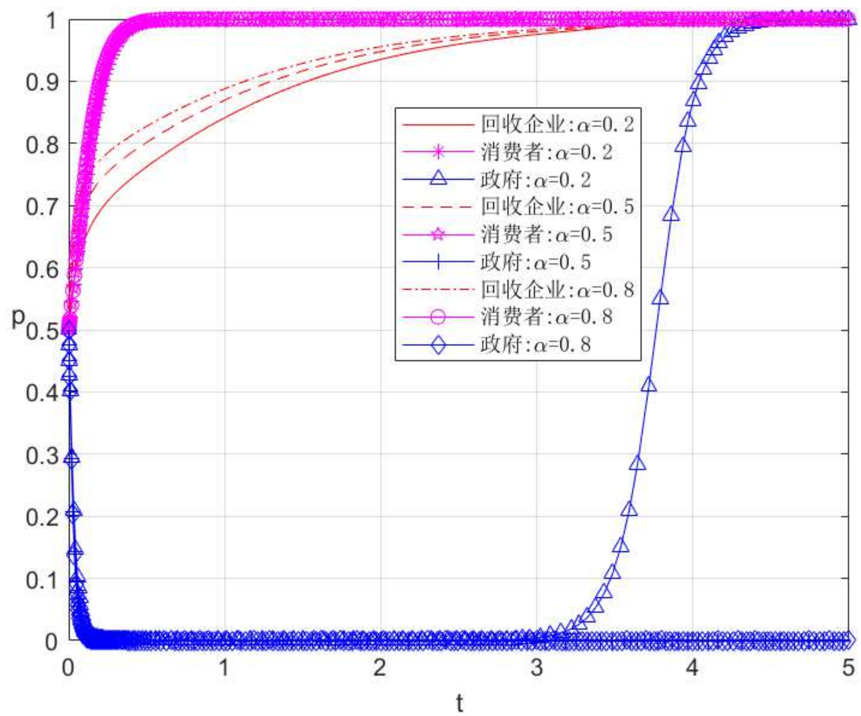


Figure 4-5 Influence of different government subsidies on the evolutionary stability strategies of participants

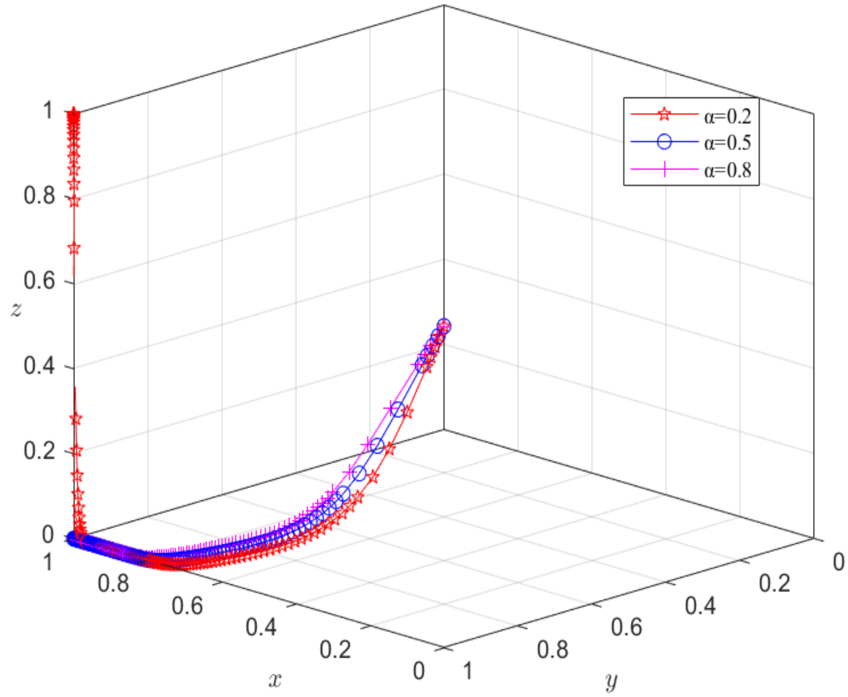


Figure 4-6 Effect of government subsidy intensity α on system evolutionary paths

The simulation results show that the three parties transform from a steady state (1, 1, 1) to an evolutionary steady state of (1, 1, 0) as the government subsidy α increases, holding other parameters constant. Increasing α increases the rate at which recycling firms actively recycle to a steady state, has a non-significant effect on the rate at which consumers tend to evolve to a steady state, and causes the government to shift from regulation to a non-regulated evolutionary steady state. This is because with the increase of government subsidies, recycling enterprises can obtain corresponding financial support, and can actively expand recycling channels and change their business methods, improve service quality, and provide more value-added services to stimulate consumers to participate in recycling business. For consumers, when enterprises make efforts for recycling business, consumers are influenced by the publicity of enterprises, and participation in recycling can get additional subsidies, so more consumers are willing to recycle their idle cell phones. However, for the government, as α continues to grow, it will evolve from a regulation to a non-regulation strategy. In the process of regulation, the government adopts reward and punishment measures for the recycling behavior of enterprises, but with the increase of subsidies, the probability of recycling enterprises choosing to actively recycle will also increase, and at the same time, the enterprises will almost never violate the law, so the probability of the government paying fines to the enterprises will also be greatly reduced. Once the government chooses to regulate, it must pay the corresponding regulatory costs, so when the subsidy reaches a certain value, the cost of government input is not proportional to the gain, the government will appear not to regulate the evolution of the strategy trend. And the larger the value, the faster the rate of development of this trend, indicating that when the government gives the recycling enterprise subsidies more than the scope of the government can receive, the government will give up regulation, which can be concluded that the strength of the subsidy α is not the larger the better. As can be seen from Figure 4-6, under the same simulation environment, the government is more sensitive to the subsidy strength, when the subsidy strength is at a certain value, the government is very willing to take the strategy of regulation, and when the subsidy strength is more than a certain value, the government will choose the strategy of non-regulation. This also reflects that in the actual situation, the government is limited rationality, for the management of used cell phone recycling at the same time also consider their own cost, and will not blindly go to invest money, the development of used cell phone recycling market needs to rely on the joint efforts of the three main bodies, in order to make the market become better and better.

4.2. Government Penalty Levels β Impact on evolutionary paths and evolutionary outcomes

Adjusting the government's punishment intensity to 0. 1, 0. 5 and 0. 9 respectively to explore the influence of the government's punishment intensity on the tripartite evolution path, and the simulation results are shown in Figures 4-7 and 4-8.

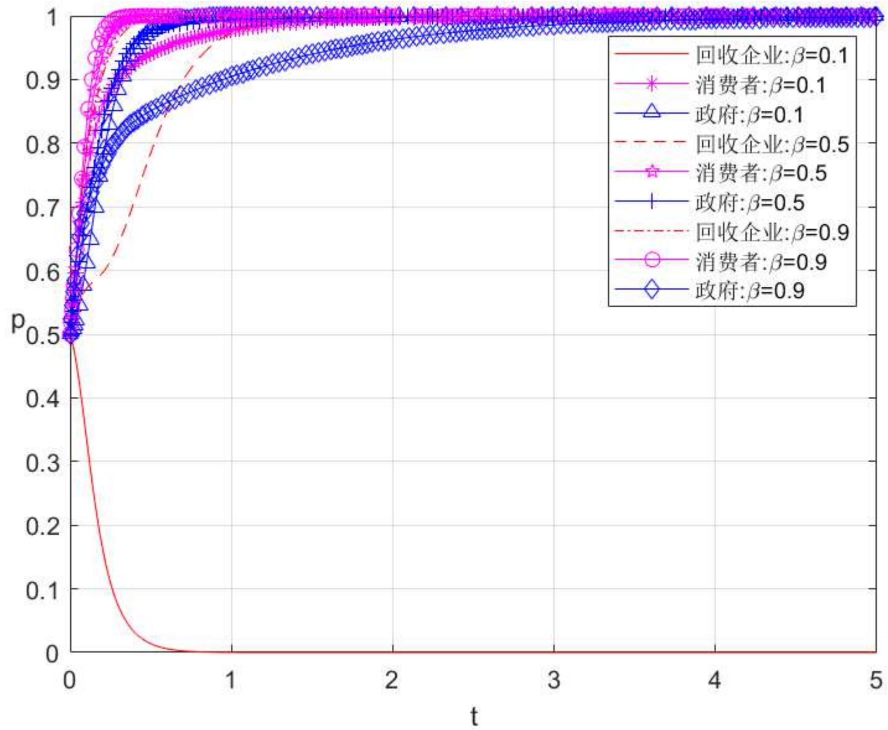


Figure 4-7 The effect of different government punishment strengths on the evolutionary stabilization strategies of participating subjects

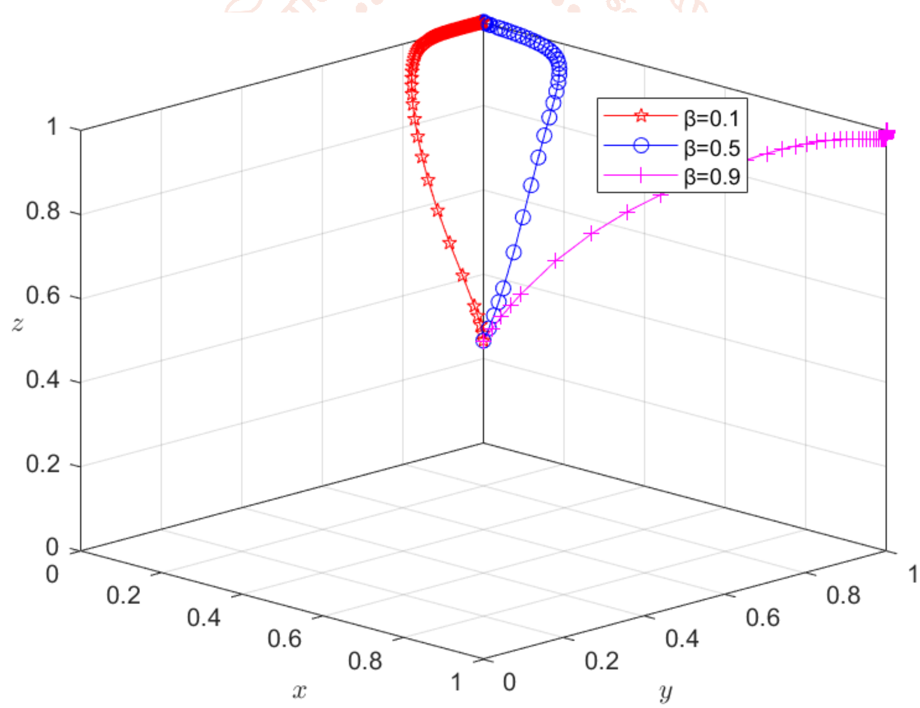


Figure 4-8 Government punishment strengths β Influence on system evolutionary path

The simulation results show that the system transforms from the stable state (0, 1, 1) to the (1, 1, 1) evolutionary stable state as the government's punishment to the recycling enterprise increases. When the punishment strength β is low, recycling enterprises tend to adopt negative recycling strategy, and as β increases, recycling firms evolve toward positive recycling strategies at an increasing rate, while consumers are always in a stable state of active participation. In the initial stage of government regulation, the government is in a weak regulatory state, and the recycling enterprises are not sensitive to the government's administrative penalties. The enterprises choose to maintain their original recycling channels and business methods, and in order to make profits, they may purchase used cell phones from unqualified vendors, dismantle them in a non-ecological way, or discharge them at will in violation of laws and regulations in the process of recycling. Even if the government discovers this, the company will continue to make profits after paying the appropriate fines, neglecting to consider consumers and the public environment.

The original single business method of recycling enterprises or possible disorderly recycling behavior is not conducive to the development of the cell phone recycling market, so the government, as the advocate and supervisor of the recycling market, will increase the penalty, improve the intensity of supervision on the recycling process of enterprises, and standardize the business process of enterprises. As can be seen in Figures 4-7, when the penalty Intensity β increases to 0. 5, the recycling enterprises begin to change their evolutionary paths and evolve toward positive recycling strategies. This is because the fines charged by the government for regulating the negative recycling process motivate the firms to develop new recycling channels and consider the consumers' wishes to actively recycle to make up for their losses. In addition, the incentives and services provided by the companies to the consumers increase the motivation of the consumers to recycle. At this point, the government gains social benefits, recycling companies gain additional revenue from word-of-mouth effects, and consumers gradually maximize their utility.

4.3. Subsidy Incentives for Recycling Firms R Impact on Evolutionary Paths and Evolutionary Outcomes

Adjust the subsidy incentive of recycling enterprises to consumers, set the value of R the value range of 5-12 to explore the impact of subsidy incentives on the three-way evolution path, and the simulation results are shown in Figures 4-9 and 4-10.

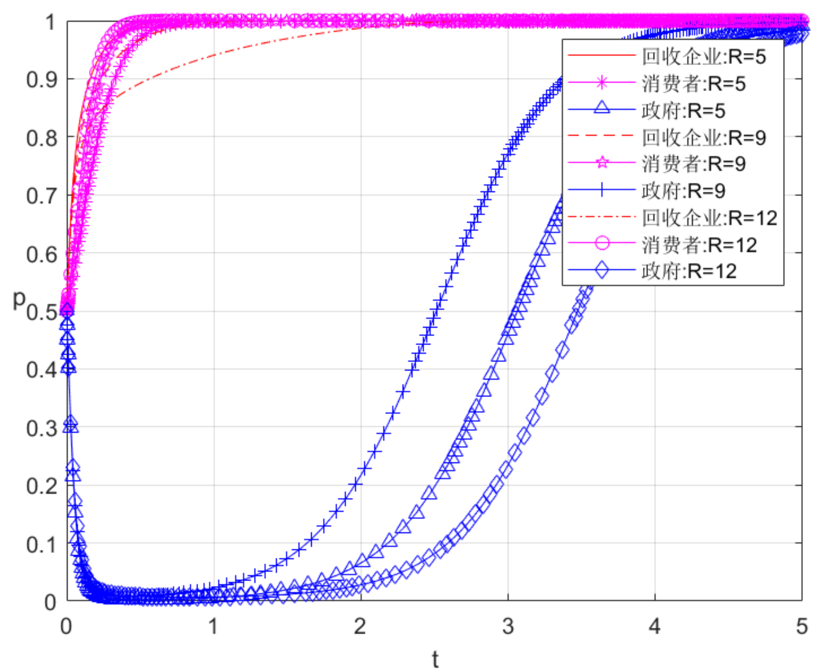


Figure 4-9 Effect of consumer subsidy incentives on the evolutionary stabilization strategies of participating agents

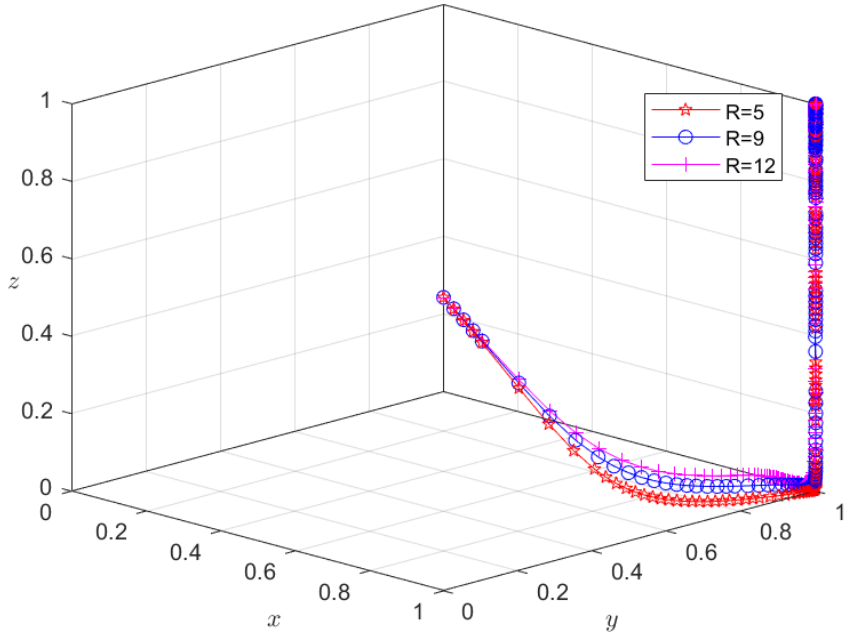


Figure 4-10 Impact of Consumer Subsidies *R* on System Evolutionary Paths

The simulation results show that the*R* Increasing from 5 to 12, the system has been a (1, 1, 1) tripartite evolutionary steady state, and for consumers, the evolution speeds up as *R* increases. For recycling companies and the government, the rate of evolution accelerates with *R* increases, it takes longer and longer for both parties to reach the steady state, and*R* once the threshold of 12 is exceeded, both recycling firms and the government change their stabilization strategies. subsidized incentives are rewards(cash coupons, discount coupons, etc.) at recycling firms give to consumers to encourage them to recycle their unused cell phones, so as the cost of subsidized incentives grows, consumers become more enthusiastic about recycling, which increases the rate of participation in cell phone recycling, and firms gain additional revenue due to word-of-mouth effects. However, as the cost of recycling becomes higher and higher, the total revenue generated by cell phone recycling decreases, until the additional revenue generated by public word-of-mouth cannot compensate for the additional cost, and the recycling company chooses to recycle in a negative way and maintain the status quo ante. In this process, the government subsidizes the enterprises to implement positive recycling, which can alleviate the financial pressure of the enterprises to a certain extent, and continuously maintain the state of positive recycling. At this time, the used cell phone recycling market maintains a positive posture. However, the government's subsidies will also increase with the increase in enterprise costs, once the subsidies paid by the government as well as the cost of regulation greatly exceeds the social benefits it can obtain, then the government will gradually give up the regulation, the same change in strategy. Even if recycling enterprises vigorously expand their channels to carry out recycling business in a variety of ways and with diversified services is the basis for the government to provide incentives, further increase in government subsidy incentives given to enterprises will lead to imbalance between government revenues and expenditures after the government subsidy incentives have reached the threshold value to drive enterprises to actively recycle.

4.4. User Privacy Concerns Coefficient λ Impact on Evolutionary Paths and Evolutionary Outcomes

The degree of concern of consumers about mobile phone privacy is adjusted to 0. 1, 0. 5 and 0. 9 respectively to explore the influence of user privacy relevance on the tripartite evolution path. The simulation results are shown in Figure 4-11 and 4-12.

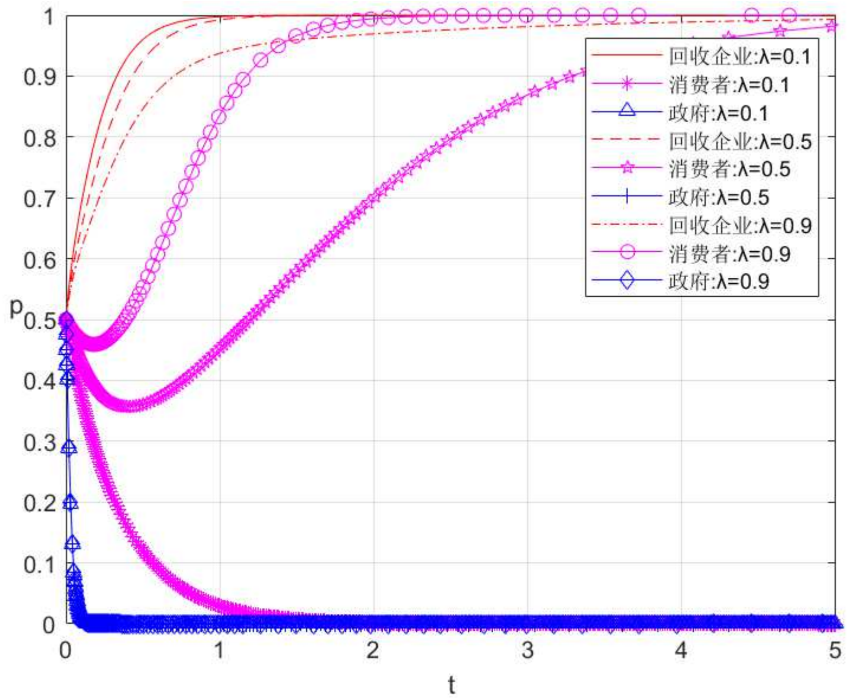


Figure 4-11 Influence of User Privacy Concerns on Evolutionary Stabilization Strategies of Participating Subjects

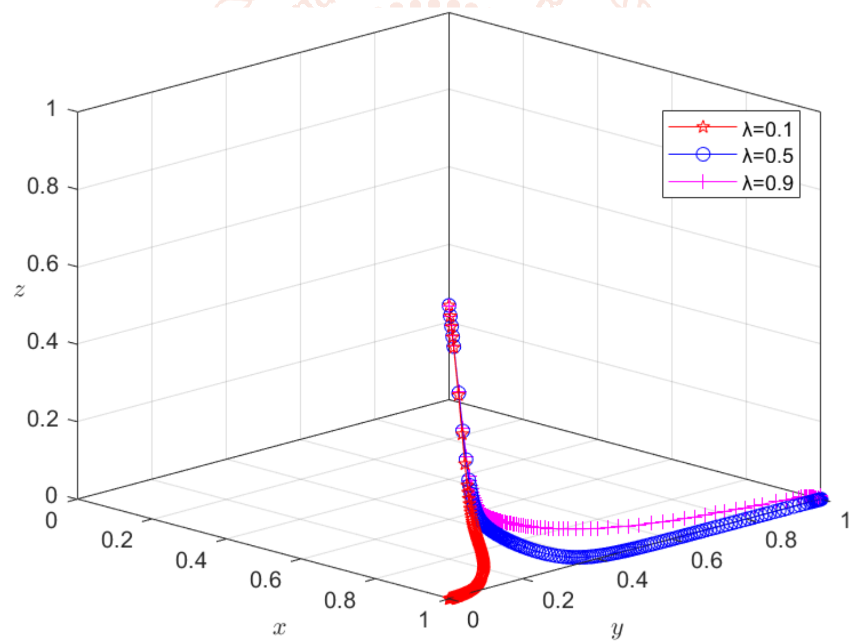


Figure 4-12 User Privacy Concerns λ Impact on system evolutionary path

The simulation results show thatλIncreasing from 0. 1 to 0. 9, the system transforms from the steady state (1, 0, 0) to the (1, 1, 0) evolutionary steady state. When the user privacy concernλ is 0. 1, consumers have low privacy concern and adopt negative participation strategies; when the level ofλincreases to 0. 5, i. e., the consumer's privacy concern level increases, its evolutionary path begins to shift toward active participation strategy, and the λ the larger it is, the faster the evolution of the consumer tends to stabilize the state. In this process, the recycling enterprise is always in the steady state of active recycling, and with the λ increases, the rate at which firms reach the stabilization strategy of active recycling slows down. This is because whether used cell phones can be effectively recycled depends to a large extent on consumers' own preferences and willingness, including their consideration of the price and service of recycling platforms, as well as their own awareness of environmental protection, sustainable development, privacy and security. Among them, the issue of cell phone privacy leakage is the main factor for consumers to choose idle cell phones. When user privacy concerns are low, consumers have almost no involvement in the recycling of cell phones, and even resell them directly to individual recyclers for short-term profit. As the level of privacy concern increases, consumers will become more interested in the services provided by recyclers in the whole process from recycling to disposal of used cell phones, especially whether the privacy treatment at each stage can truly guarantee privacy security. In order to promote the recycling business, recycling enterprises implement the privacy shredding technology program in all aspects for the privacy issues of consumers' concern, adopt the data filling and repeated erasure method in line with the international ACI standard to ensure that it cannot be recovered, ensure that the cell phone is truly cleared of users' personal privacy from the recycling of consumers' cell phones to the final refurbishment and dismantling, and provide feedback to consumers on the privacy destruction report. In short, with the enhancement of consumer privacy and security awareness, coupled with the recycling companies through the provision of discarded cell phone related environmental protection information is conducive to consumers to understand the formal channels of recycling of cell phones dual resource and environmental benefits and the hazards of informal recycling, and continue to improve the technical level of the handling of e-waste information in a more intuitive way to consumers to show the company's privacy policy and information processing technology, so as to reach the enterprise, Consumers can actively cooperate with each other to promote the recovery of cell phones, realize the recycling of resources, and obtain the double benefits of economy and environment, and the government can also reduce the degree of intervention and save the cost of regulation of the used cell phone recycling market.

5. Conclusion

This paper constructs an evolutionary game model among local governments, recyclers and consumers, and analyzes the stability of strategy choices and strategy combinations of each participant, as well as the influence relationship among the elements, determines the conditions under which each party reaches a stable strategy in the recycling process of used and end-of-life cellular phones, and through numerical simulation, explores the impacts of the government's subsidy strength, the government's punishment strength, the recycling enterprise's subsidy incentives, and the user's privacy concern coefficients on the evolutionary paths and evolutionary outcomes of the participants. The study shows that government subsidy and punishment affect the probability of recycling enterprises to realize active recycling strategy, and the subsidy incentive of recycling enterprises to consumers can increase the willingness of consumers to participate in the recycling of used cell phones. However, there is an upper limit to both the government's rewards and penalties and the recycling companies' subsidies and incentives for consumers, and subsidies, fines, and incentives that exceed the upper limit will lead to the development of both the government and the companies in a direction that is not conducive to the stability of the cell phone recycling market. In addition, as consumers themselves pay more attention to the privacy of cell phone recycling, recycling companies provide better services, which in turn stimulates them to improve their service level and provide more value-added services to attract consumers to recycle their used cell phones. As both companies and consumers evolve towards positive strategies, the government can reduce regulatory efforts and costs to achieve a win-win situation for all three parties.

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