



Dump or recycle? Consumer's environmental awareness and express package disposal based on an evolutionary game model

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Abstract

Along with the rapid development of the express industry and the inevitable trend of sustainable development, the disposal of express packaging is an urgent problem that needs to be solved. With the objective to the effective disposal mode for express packaging, this paper introduces the consumers' environmental awareness into the framework and establishes an evolutionary game model to explore the governing measures of the express packaging recycling industry. It is found that without considering consumers' environmental awareness, the government's reward and punishment mechanism alone cannot restrain the recycler's decision-making effectively, while the participation of the consumers with environmental awareness could drive the strategy of the recycler to converge to the ideal state effectively, which is recycling the express packaging actively. The sensitivity analysis shows that the participation of consumers with environmental awareness significantly weakens the recycling difficulty and reduces the recycling cost of the recycler, which is helpful to improve the willingness of the recycler to recycle the express packaging continually. Thereby, the express packaging recycling industry can be improved better when the consumer's awareness of environmental protection is enhanced.

Keywords Express packaging recycling · Environmental awareness of consumers · Reward and punishment mechanism · Evolutionary game model

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1 Introduction

The blooming of e-commerce and the express delivery business have brought considerable convenience to daily life, while the disposal of used express packing in society is becoming one of the most concerning issues around the world (Lin et al., 2021). The number of express delivery businesses in China has been growing rapidly over the years (Fig. 1). For example, in 2019, the number of china reached 63.52 billion, achieving an increase of 25.3% over the previous year. Since 2020, under the influence of COVID-19, there is a rapidly growing tendency of online shopping which promotes the express delivery business increase sharply. Especially, during the "Double Eleven online shopping dwarfs" in 2020, China's national postal and express enterprises have handled 3.965 billion expresses in 11 days from November 1 to 11. More than 9 million tons of paper waste and 1.8 million tons of plastic waste are generated in China's express industry every year (Su et al., 2020). The excessive growth of express packaging not only produces great packages waste but also causes serious environmental pollution (Fan et al., 2017; Li & Zhao, 2018). For instance, the plastic fraction in express contains 28%-92% of fossil carbon, which may release 11.4–3.4 tons of carbon dioxide from the incinerated of 1 ton of dry plastic waste (Lin et al., 2021). At the same time, there is a significant risk of leaking plastic waste into the environment which easily leads to huge damages to the ecosystem (Villarrubia-Gomez et al., 2018). However, even though 80% of the cardboard is recycled for reuse, most of the plastics, paper, and envelopes are incinerated or landfilled as municipal solid wastes due to their poor recyclability (Greenpeace, 2019). These situations caused not only considerable environmental pollution and wasting recyclable resources, but also the expensive cost of waste management.

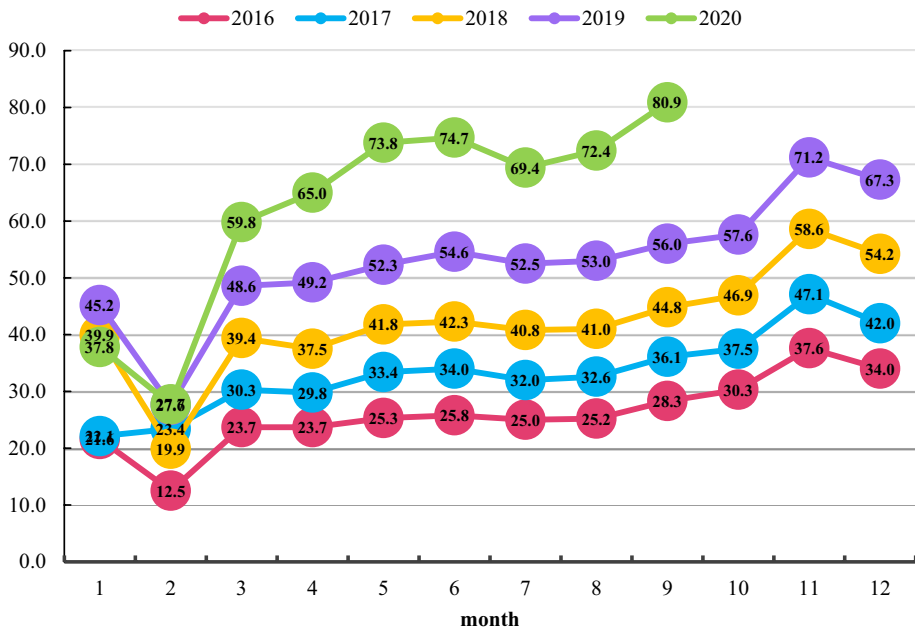


Fig.1 The volume of express delivery business in China

Consequently, it is urgent to improve the recycling of express packaging and form its circular economy disposal mode.

To improve express packaging disposal, some efforts have been put into relevant industries. For example, SF Express has made steps to improve packaging standardization and simplification, which brought outstanding achievement in its recycling performance (Ren et al., 2019). New modes and technologies for recycling express packaging have also been explored, such as shared express packaging (Liu & Wang, 2019) and asphalt performance-enhanced modifiers made from waste express tape (Yu et al., 2019). With the principles of circular economy, governments have taken measures to improve the treatments of express packaging. For instance, the State Post Bureau of China issued *The Implementation Plan to Promote Green Packaging in the Express Delivery Industry* in 2016, which set the goal of completing the socialized express package recycling system. The purpose of the plan is not only to encourage express enterprises to use easily recyclable packaging materials but also to promote the manufacturers, users, and consumers to participate in the packaging classification and recycling. In 2017, the State Council of China issued *The Implementation Plan for the Extended Producer Responsibility System*, which specified that by 2025, the proportion of recycled raw materials for key products would reach 20%, and the standard recovery and recycling rate of waste and discarded products would reach 50%. In October 2020, Shanghai incorporated the green treatment of express packaging into its *Implementation Plan of Strengthening Plastic Pollution Control*. Through these economic and administrative efforts, the governments and enterprises tried to promote the disposal of the express packing and alleviate the wastage of resources as soon as possible.

In terms of recycling, many researchers have investigated from the perspective of reverse logistics (Prajapati et al., 2019). Reverse logistics refers to the reprocessing and resale of used packing or raw material to bring them back to the market (Long et al., 2019), which has three types: recycling by manufacturers, joint recycling by multiple parties (including governments, manufacturers, retailers, consumers, etc.), and third-party management. Accordingly, the recycling of express packaging is a systematic project with multiple participants that have different interests and objectives. Given the urgent requirement on the circular economy, government plays an important role in recycling express packaging (Zhang et al., 2016). As the policymaker and regulator, the government has taken measures to regulate recycling express packaging, including awards and plenty incentives, where their impacts of them are investigated in many studies (Heydari et al., 2017; Li et al., 2018a; Li et al., 2018b; Wang et al., 2017; Zhao et al., 2018; Zhu et al., 2017). However, best to our knowledge till now, few studies have investigated the coordination of governmental incentives and recyclers considering the consumers' environmental awareness in recycling express packaging. Apart from that, like the terminal of the supply chain, consumers are also important participants in recycling express packaging (Gadennan et al., 2011; Meherishi et al., 2019). It is proved that there is a significant correlation between recycling and green consumption behavior (Arslan et al., 2012; Yu et al., 2016; Zhao et al., 2014). What's more, consumers' environmental awareness has been confirmed as an important driving factor in green consumption, as well as the disposal of the packaging (Amyx et al., 1994; Van Birgelen et al., 2009). The improvement of consumers' awareness of environmental protection may not only affect the cost of recyclers significantly but also change the demand function of the market (Rhein & Schmid, 2020). However, the mechanism of environmental protection consciousness of consumers in the express packaging recycling industry is still unclear. In addition, the decision-makers are often bounded rational actually, while the optimal recycling strategies and the proper incentives that consider them are also absent in the literature.

All these research gaps restrict the analysis of recycling express packaging for various scenarios and strategies. Without a proper game model, it is hard to explore the proper incentives and to identify how they affect the recycling modes. Motivated by these issues, this study aims to explore the optimal strategies of the recycler and the government's incentives in the express packaging recycling industry from the micro-perspective and then investigate the mechanism of consumers' environmental awareness on behavior evolution in the express packaging recycling industry. Therefore, this study employs an evolutionary game model to analyze the recycling express packaging considering consumers' environmental awareness. Moreover, the impacts of government incentives mechanisms on the consumers' environmental awareness are tested. Also, for the incentives mechanism, the recycling difficulty and the cost of supervision are considered in the model. Along with these novelties, this paper focuses on solving the following questions.

(1) How to introduce the environmental awareness of consumers into the model to develop a novel evolutionary game model of the express packaging recycling industry?

(2) What are the payoff matrices of the government and the recycler in the evolutionary game model of the express packaging recycling industry? And what are the evolutionary stability strategies and their conditions in the evolutionary game model?

(3) How can we illustrate the dynamic changes of the participants' strategies? And how can we design the regulations to improve the express packaging recycling industry?

Guided by these research questions and with the objective to find the effective disposal mode for express packaging recycling, this paper tries to develop a game model considering consumers' environmental awareness and explored the strategic choices and coordination between government incentives and recyclers in the express packaging recycling industry. To answer these research questions, this paper builds an evolutionary game model for the recycling express packaging industry, in which the consumers' environmental awareness is considered as a factor in determining the difficulty of recycling. Employing the model as a tool, this paper explores the dynamic process of government incentives and recyclers' strategy coordinate in the recycling express packaging industry. Through simulations of the model, this paper conducts sensitivity analysis to investigate the driving factors on the coordination of government incentives and recyclers' strategy. It was found that the consumers' environmental awareness can strengthen the effect of government incentives, thereby promoting express packaging recycling effectively. The present study enriches the literature on the coordination of government incentives and recyclers' strategies in the resources recycling issues.

The rest of this paper is arranged as follows. The literature review is presented in Sect. 2. Section 3 constructs evolutionary game models and analyzes evolutionary stability strategy. Sect. 4 contains the numerical simulation and sensitivity analysis. And the discussion of the results is presented in Sect. 5. Finally, conclusion and suggestions are provided in Section 6.

2 Literature review

This review part covers the three important elements in the fields of recycling express packing disposal issues, namely, government incentives, consumers' environmental awareness in recycling, and decision-making in reverse logistics based on evolutionary game theory, which is the theoretical background of this study.

2.1 Incentives on recycling

As the regulator and the policymaker, government plays an effective role in encouraging recycling activities, as well as the participants to conduct reverse operations and environmental-friendly behaviors (Rathore & Sarmah, 2021). There is a growing body of research on the effects of the reward and punishment mechanism in recycling resources. For example, Ma et al. (2013) investigated the function of consumption subsidy in a dual-channel supply chain, which proved that all the participants could benefit from them. Hong et al. (2014) explored the government subsidy in recycling and disposal of end-of-life products. Wang et al. (2015) proposed that increasing the intensity of incentives and penalties could be helpful to improve the collection of waste products. And the quantity discount and fee increase contract proposed by Heydari et al. (2017) point out that the government could improve and coordinate the reverse supply chain by offering different incentives (tax exemption and subsidy) to supply chain enterprises. Wang et al. (2017) and Wang et al. (2018) explored the influence of the reward and punishment mechanism between two continuously competing manufacturers on the recycling rate. With the existence of technology spillover effect and recycling competition, Li et al. (2018a) and Li et al. (2018b) dig out the mutual influence between reward and punishment mechanism and innovation R&Ds decision of recycling merchants. Zhu et al. (2017) and Li et al. (2018a), Li & Zhang et al. (2018b) analyzed how the subsidy policy works on the recycling of used products. Furthermore, Tang et al. (2018) establish three competitive dual-channel recycling models and tested their effects on manufacturers' recycling strategies through the government reward and punishment mechanism. In this study, we also consider the government incentives consisting of reward and punishment. Nevertheless, we extend the prior researches to address the dynamic process in the recycling express packaging under government incentives, which is one focus of this study.

2.2 Consumers' environmental awareness in recycling

Consumers' green environmental awareness is another element that affects the recycling of resources (Wang et al., 2020). In fact, it is not only the responsibility of recyclers and the government to solve the problem of wasted resources caused by express packaging, nor can we rely on scientific and technological means to invent more environmentally friendly packaging materials. Consumers in the terminal of express delivery are also important participants in need of taking responsibility for recycling express packaging (Gadannen et al., 2011). A number of researches have investigated the effects of consumers on recycling resources. For instance, Zhao et al. (2014) and Yu et al. (2016) pointed out that green consumption behaviors have significant impacts on recycling resources. Lu et al. (2020) confirm that the consumers' preference is an important factor in recycling packaging. Since consumers' usage intention depends on their attitude and perceived behavioral control significantly, consumers with strong environmental awareness will consciously keep the express package in good condition for recycling (Cao & Liu, 2019; Wang et al., 2021). Consumers who have environmental awareness prefer environmentally friendly behaviors, which motivate manufacturers and retailers to develop green images and environmental products (Dong et al., 2019; Iles, 2008). And it was found that consumption generated from the consumers' environmental awareness could benefit the disposal of the packaging (Amyx et al., 1994; Van Birgelen et al., 2009). The improvement of consumers' awareness

of environmental protection may not only affect the cost of recyclers significantly but also change the demand function of the market (Rhein & Schmid, 2020). Although the above studies explore the consumers' awareness impacts on the recycling resources, the mechanism of consumers' environmental awareness affects the recycling express packaging are still unclear, which is another focus of this study.

2.3 Decision-making in reverse logistics

Reverse logistics is the process that products are collected from customers through various operations, such as repairing, refurbishing, remanufacturing, recycling, and disposing of environmentally friendly modules (Soleimani & Kannan, 2015). It aims to reduce the negative effects of improper waste disposal on the environment from material extraction and manufacturing to the final consumer (Campos et al., 2017). In the torrent of sustainable development, reverse logistics has become a fundamental element of supply chain management to maintain profitability in a competitive business, as it demonstrates the company's commitment to environmental sustainability (Khor & Udin, 2013; Singhry, 2015). One sustainable business operation involves activities related to the reusing of resources collected through reverse logistics (Chen et al., 2019). More and more scholars have studied reverse logistics, which can be divided into three groups, which are the network of reverse logistics (Tosarkani et al., 2020; Xu et al., 2021), the factors and performance of reverse logistics (Donner et al., 2020; Lamba et al., 2020), the inventory control of reverse logistic (Ben-Daya et al., 2019; Yang et al., 2018). Most of these researches focus on network construction and inventory control. However, for many firms, the more important task is to choose the most suitable reverse logistic mode to balance the benefits and costs of building or participating in reverse networks.

Given that reverse logistics networks are operated by multiple stakeholders, coordination among stakeholders and their decision-making are the keys to the success of reverse logistics. On the one hand, there are methods proposed as the criteria decision-making of the stakeholders. For example, AHP is widely used as the typical multi-criteria decision-making method in reverse logistics (Deng et al., 2014; Udaeta et al., 2016). Further to this, the fuzzy AHP, Mixing AHP, TOPSIS are also been used as methods to explore the considerations in the application of reverse logistics (Chiou et al., 2012; Senthil et al., 2012; Jung, 2017). On the other hand, the strategy adoption of the stakeholders is also investigated, with game theory widely used. For instance, Savaskanand Van Wassenhove (2006) have employed a game model to investigate the selection of the best reverse logistics. Huang et al. (2013), Maiti and Giri (2017) used game theory to evaluate the performances of the supply chain. However, these studies examined the strategies of complete rational participants in the supply chain, but they ignored the dynamic interactive process in the participants' decision-making process, as well as the behavior characteristics of the participants' learning and strategy adaption.

In the research of the dynamic interaction of multiple participators' behaviors at the micro-perspective, the evolutionary game model has turned out to be an effective tool (Babu & Mohan, 2018; Chen & Hu, 2018). Unlike the traditional game theory, which focuses on the static equilibrium, the evolutionary game theory emphasizes the dynamic process of the system reaching equilibrium and the specific development changes (Friedman, 1991), which could reveal participators' learning, competition, strategy adjustment, and other phenomena in the process of the game (Taylor & Jonker, 1978). Accordingly, unlike the traditional game model, which assumes the participators to be completely

rational, the evolutionary game model emphasizes that the participator is bounded rational, which means that they could seek their optimal strategies by continuous games (Weibull, 1997), which fits the reality better. At present, the evolutionary game model has begun to be applied to the research of waste recycling. For example, Shen et al. (2018) use the evolutionary game model to analyze the recycling behaviors of contractors and manufacturers in the management of construction materials. Chen et al. (2019) applied evolutionary game theory to figure out the strategy selection of manufacturers' recycling under different reward and punishment mechanisms of the government. Su (2020) and Wang et al. (2020) develop evolutionary game models to find the strategy choices of the government, the recyclers, and the consumers in e-waste recycling and construction waste recycling, respectively. With the evolutionary game theory applied to analyze the issues with bounded rational players, Gu et al. (2019) developed an evolutionary game model to investigate the cooperation in reverse logistics. Considering that express packaging recycling is a reverse logistics operation, these researches provide a great reference for investigating the strategy choices and the driving factors of the participators in the express packaging recycling industry.

From the literature review, it can be observed that researchers have made a strong contribution to the field of recycling used materials and waste. They have also explored the impacts of consumers' environmental awareness, government subsidy, punishment on recycling packaging by comparing the various scenarios. But till now, there is little literature that concentrates on analyzing the strategy the dynamic interaction between government incentives and recycler's strategies in recycling express packaging. Also, the consumers' environmental awareness is rarely considered in the field of disposal of express packaging. Therefore, this study employs an evolutionary game model for investigating the dynamic coordination between the government incentives and recyclers strategies in recycling express packaging, as well as the mechanism of consumers' environmental awareness. Moreover, this study has also investigated the evolutionary path of their strategies, as well as the driving factors by sensitivity analysis. Thus, the proposed study fulfills the identified gaps in the literature and made its contribution.

3 Methods and modeling

3.1 Methodological procedures

This paper employs an evolutionary game model to explore the issues of recycling express packaging considering consumers' environmental awareness. As an important branch of game theory, evolutionary game theory surpasses the limitations of traditional game models which assume that participants are perfectly rational and well-informed. The evolutionary game model focuses on the dynamic adaptation process of the strategy of the bounded rational player group until the player finds its evolution stability strategy (Friedman, 1991). This feature gives it an unparalleled advantage over traditional game models in resolving the dynamics of the equilibrium state of a game system.

Specifically, in the given size of the game group, the evolutionary game model could reveal the game process that players learn, compete and adapt their strategies in multiple repeated games (Taylor & Jonker, 1978). The replicated dynamic equation is the tool by which the evolutionary game model describes these processes. A replicated dynamic equation is a dynamic differential equation that describes the frequency with which a particular

strategy is adopted by the players' group. The replicated dynamic equation for a decision group with A and B strategies can be written as

$$F(x) = \frac{dx(t)}{dt} = x(f_A - f) \quad (1)$$

where x is the proportion of individuals who adopt strategy A in the game, f_A is the payoff when strategy A is adopted and f is the average payoff.

The equilibrium point that satisfies $F(x) = 0$ is the stable point of this replicated dynamic equation. That is, the decision-maker's strategy corresponding to the stable point satisfying $d^2x(t)/dt^2 < 0$ is the evolutionary stable strategy (ESS). According to Friedman (1991), the ESS can be determined based on the Jacob matrix (J) of the game system. Specifically, the equilibrium point is an ESS when $tr(J) < 0$ and $\det(J) > 0$ are satisfied, where $\det(J)$ is the determinant of the Jacob matrix and $tr(J)$ is the trace.

In addition, simulation is a common tool for capturing the path of the ESS and the stability of evolutionary game models visually. It can be conducted based on the transformed equation which is a discretized replicated dynamic equation, as shown in (2).

$$F(x) = \frac{dx(t)}{dt} \approx x(t)(1 - x(t))(f_A - f) \quad (2)$$

3.2 Problem description and assumptions

This paper focuses on an express packaging recycling industry with a reward and punishment mechanism considering the environmental awareness of consumers, which mainly involves the government and the recyclers. Specifically, under the government incentives of reward and punishment, the government plays the role of the regulator by setting the expected target recycling rate for recyclers (Wang et al., 2015). When the recycling rate the recycler achieves exceeds the target rate, the strategy of the recycler can be considered as an actively recycle strategy, and the government will give the recyclers some subsidy. Otherwise, it can be treated as a negatively recycle strategy and the government will issue a fine for it. Meanwhile, as the terminal of the e-commerce, consumers determine the difficulty of the express packaging recycling by their consumption behaviors directly. Consumers with environmental awareness have strong enthusiasm to take action in express packaging recycling. They are willing to take the initiative to deal with express packaging reasonably, such as not violent dismantling packaging, keeping the used packages in good conditions for recycling, correct classification of garbage, to reduce the recycling difficulty of recyclers (Wang et al., 2020). To concentrate on the interaction between the government incentives and the recyclers strategies, the consumers with environmental awareness are set as the external factors.

On the basis of the relationships among the government, the recycler, and the consumers analyzed above, we make some necessary assumptions as follows.

- (1) The recyclers and the government are bounded rationality. Both of them can learn and adapt to the dynamic changes of the game system and then adjust and optimize their strategies during the process of the evolutionary game.
- (2) The strategy set of government is $S_1 = \{\text{supervise, not supervise}\}$, and the probability of "supervise" adopted is x ($x \in [0, 1]$), the probability of "not supervise" adopted is $1 - x$. Correspondingly, the strategy set of recyclers is $S_2 = \{\text{actively recycle, negatively}$

- recycle}, and the probability of “actively recycle” adopted is y ($y \in [0, 1]$), the probability of “negatively recycle” adopted is $1 - y$.
- (3) The recycling rate of the recyclers is T , and the recycling cost is a convex function of the recycling rate $C = cT^2$, where c ($c \geq 0$) refers to the recycling difficulty coefficient (Wang et al., 2015⁷). Hence, the increase of recycling rate will lead the cost of recycling cost increase sharply.
 - (4) The consumers with environmental awareness are external participants on the marker, whose participation can help reduce the recycling difficulty of the recycler from c to $(1 - \lambda)c$, where λ ($\lambda \in [0, 1]$) refers to the coefficient of consumers’ environmental awareness. Thus, the higher the level of environmental awareness of consumers is, the more significant reduction in the difficulty of recycling for recyclers will be.
 - (5) The target recycling rate set by the government is T_0 ($T \in [0, 1]$), and the reward or punishment intensity of the government for recyclers’ recycling efficiency is k ($k > 0$) (Chen et al., 2019; Wang et al., 2015). So, the government will give rewards $k(T_1 - T_0)$ to the recycler for its strategy of “actively recycle”, while the government will punishments $k(T_0 - T_2)$ for its strategy of “negatively recycle”.
 - (6) The government pays the supervision cost and obtains the positive effect on the environment caused by recycling waste express packaging. When the recycler chooses to actively recycle, the positive effect is W_1 , and the effect is W_2 when the recycler chooses to negatively recycle.
 - (7) The parameters and descriptions are summarized in Table 1.

3.3 Modeling and solutions

Based on the problem description and assumptions, there are four strategy combinations in the game model, which are (supervise, actively recycle), (supervise, negatively recycle), (not supervise, actively recycle) and (not supervise, negatively recycle). Then the payoffs of the recycler and the government in four strategy combinations can be obtained. Take the

Table 1 Parameters and descriptions

Parameters	Descriptions
W_1	The positive environmental effect is obtained by the government when recyclers actively recycle
W_2	The positive environmental effect is obtained by the government when recyclers negatively recycle
C_g	The implementation cost of government supervision when it chooses to supervise
k	The reward or punishment intensity of government for recyclers
T_1	The recycling rate when recyclers choose actively recycle
T_2	The recycling rate when recyclers choose to negatively recycle
R_1	Revenue earned when recyclers actively recycle
R_2	Revenue earned when recyclers negatively recycle
C	The total recycling cost of the recyclers
c	The coefficient of recycling difficulty
λ	The coefficient of consumers’ environmental awareness

strategy combination (supervise, actively recycle) as an example. The government can get a positive environmental effect W_1 , and pay the implementation cost of government supervision and subsidy $C_g + k(T_1 - T_0)$ at the same time. Hence, the payoff of the government is $W_1 - C_g - k(T_1 - T_0)$. Correspondingly, the recycler can get the revenue from its actively recycling R_1 and the $k(T_1 - T_0)$, and pay the recycling cost $(1 - \lambda)cT_1^2$ at the same time. Therefore, the payoff of the recycler is $R_1 - (1 - \lambda)cT_1^2 + k(T_1 - T_0)$. Similarly, we can obtain the payoffs of the recycler and the government in other strategy combinations. And the payoff matrix is shown in Table 2.

According to Table 2, we can get the expected revenues of the government and the recycler. The expected benefits of local governments choose to supervise are:

$$\begin{aligned}
 U_{11} &= y[W_1 - C_g - k(T_1 - T_0)] + (1 - y)[W_2 - C_g + k(T_0 - T_2)] \\
 &= yW_1 + (1 - y)W_2 - yk(T_1 - T_0) + (1 - y)k(T_0 - T_2)
 \end{aligned}
 \tag{3}$$

The expected benefits of local governments choose not to supervise are:

$$U_{12} = yW_1 + (1 - y)W_2
 \tag{4}$$

The average expected benefits of the government are:

$$\bar{U}_1 = xU_{11} + (1 - x)U_{12}
 \tag{5}$$

The expected benefits of recyclers choose actively recycle are:

$$\begin{aligned}
 U_{21} &= x[R_1 - (1 - \lambda)cT_1^2 + k(T_1 - T_0)] + (1 - x)[R_1 - (1 - \lambda)cT_1^2] \\
 &= R_1 - (1 - \lambda)cT_1^2 + xk(T_1 - T_0)
 \end{aligned}
 \tag{6}$$

The expected benefits of recyclers choose negatively recycle are:

$$\begin{aligned}
 U_{22} &= x[R_2 - (1 - \lambda)cT_2^2 - k(T_0 - T_2)] + (1 - x)[R_2 - (1 - \lambda)cT_2^2] \\
 &= R_2 - (1 - \lambda)cT_2^2 - xk(T_0 - T_2)
 \end{aligned}
 \tag{7}$$

The average expected benefits of the recyclers are:

$$\bar{U}_2 = yU_{21} + (1 - y)U_{22}
 \tag{8}$$

Table 2 The evolution game matrix between the government and recyclers without consumers

Players		Recycler	
		Actively recycle (y)	Negatively recycle ($1 - y$)
Government	Supervise (x)	$W_1 - C_g - k(T_1 - T_0)$ $R_1 - (1 - \lambda)cT_1^2 + k(T_1 - T_0)$	$W_2 - C_g + k(T_0 - T_2)$ $R_2 - (1 - \lambda)cT_2^2 - k(T_0 - T_2)$
	Not supervise ($1 - x$)	$W - 1$ $R_1 - (1 - \lambda)cT_1^2$	W_2 $R_2 - (1 - \lambda)cT_2^2$

3.3.1 Replicated dynamic system

According to Eqs. (3) and (4), the replicated dynamic equation of the government adopting the strategy of “supervise” can be obtained as follows:

$$L(x) = \frac{dx}{dt} = x(1 - x)(U_{11} - U_{12}) = x(1 - x)[-C_g - yk(T_1 - T_0) + (1 - y)k(T_0 - T_2)] \tag{9}$$

According to Eqs. (6) and (7), the replicated dynamic equation of the recycler adopting the strategy of “actively recycle” can be obtained as follows:

$$L(y) = \frac{dy}{dt} = y(1 - y)(U_{21} - U_{22}) = y(1 - y)[R_1 - R_2 - (1 - \lambda)c(T_1^2 - T_2^2) + xk(T_1 - T_2)] \tag{10}$$

The replicated dynamic system is composed of differential equations Eq. (9) and Eq. (10). Let the replicated dynamic system equal to 0, we can get five equilibrium points which can be obtained as (0, 0), (0, 1), (1, 0), (1, 1) and (x_0, y_0) , where $x_0 = \frac{R_2 - R_1 + (1 - \lambda)c(T_1^2 - T_2^2)}{k(T_1 - T_2)}$, $y_0 = \frac{k(T_0 - T_2) - C_g}{k(T_1 - T_2)}$.

These equilibrium points are not necessarily the ESS. Only if the stable point of the replicator dynamic equation is an evolutionary equilibrium, the locally asymptotically stable point (ESS) (Friedman, 1991). And the stability of the equilibrium points is determined by the determinant of the Jacobian matrix and its trace, where the Jacobian matrix is expressed as Eq. (11):

$$J = \begin{bmatrix} \frac{\partial L(x)}{\partial x} & \frac{\partial L(x)}{\partial y} \\ \frac{\partial L(y)}{\partial x} & \frac{\partial L(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} (1 - 2x)[-C_g - yk(T_1 - T_0) + (1 - y)k(T_0 - T_2)] & x(1 - x)[-k(T_1 - T_2)] \\ y(1 - y)[k(T_1 - T_2)] & (1 - 2y)[R_1 - R_2 - (1 - \lambda)c(T_1^2 - T_2^2) + xk(T_1 - T_2)] \end{bmatrix} \tag{11}$$

Thereafter, we introduce the five equilibrium points into the Jacobian matrix and analyze the stability of them with or without considering the consumer’s environmental awareness. The analysis of the local asymptotic stability of each equilibrium point is shown in Table 3.

3.3.2 The stability analysis considering the worst consumer’s environmental awareness

Considering the consumers have the worst environmental awareness in express packaging recycling, that is the difficulty of recycling cannot be reduced, at this time $\lambda = 0$. It can be found from Table 3 that there are two possible cases in the evolutionary game model.

Case 1: When $R_1 - cT_1^2 > R_2 - cT_2^2$, that is, the net profit the recycler could get from the strategy of “actively recycle” is greater than the strategy of “negatively recycle”. Here, (0, 1) is the only evolutionary stability strategy (ESS) of the game model as shown in Table 3. Meanwhile, the stable strategy combination is {not supervise, actively recycle}, which means that the recycler is willing to choose the “actively recycle” strategy without the government’s supervision.

Case 2: When $R_1 - cT_1^2 < R_2 - cT_2^2$, that is, the recycler could not benefit more from the strategy of “actively recycle” than the strategy of “negatively recycle”. According to

Table 3 The stability of the equilibrium points

Equilibrium point	$\lambda = 0$						$\lambda > 0$		
	$R_1 - cT_1^2 > R_2 - cT_2^2$			$R_1 - cT_1^2 < R_2 - cT_2^2$			$R_1 - cT_1^2 < R_2 - cT_2^2$		
	det(J)	tr(J)	Stability	det(J)	tr(J)	Stability	det(J)	tr(J)	Stability
(0, 0)	+	+	Unstable point	-	N	Saddle point	-	N	Saddle point
(1, 0)	-	N	Saddle point	-	N	Saddle point	-	N	Saddle point
(0, 1)	+	-	ESS	-	N	Saddle point	N	N	Uncertain
(1, 1)	-	N	Saddle point	-	N	Saddle point	-	N	Saddle point
(x_0, y_0)	\	\	Meaning-less	N	N	Asymptotically stable point	N	N	Asymptotically stable point

* “+” means positive, “-” means negative, “N” means uncertain

Table 3, the evolutionary path of the evolutionary game system cannot reach the evolutionary stability strategy (ESS), and (x_0, y_0) is the asymptotically stable point. These results show that the reward and punishment mechanism of the government cannot effectively encourage the recycling behavior of recyclers.

Furthermore, we can discuss the influence of relevant decision variables on the evolving stability strategy between government and recyclers by taking the partial derivatives to them, such as the reward and punishment intensity of the government (k), the implementation cost of government supervision (C_g) and the coefficient of recycling difficulty (c) separately.

- (1) $\frac{\partial x_0}{\partial k} < 0$, x_0 decreases as k increases; it indicates that the probability of government supervises decreases with the increase of reward and punishment intensity, and vice versa.
- (2) $\frac{\partial y_0}{\partial k} > 0$, y_0 increases as k increases; it indicates that the probability of recyclers actively recycling increases with the increase of reward and punishment intensity, and vice versa.
- (3) $\frac{\partial x_0}{\partial C_g} < 0$, x_0 decreases as C_g increases; it indicates that the probability of government supervises decreases with the increase of government regulation cost, and vice versa.
- (4) $\frac{\partial y_0}{\partial C_g} < 0$, y_0 decreases as C_g increases; it indicates that the probability of recyclers actively recycling decreases with the increase of government regulation cost, and vice versa.
- (5) $\frac{\partial x_0}{\partial c} > 0$, x_0 increases as c increases; it indicates that the probability of government supervises decreases with the increase of the coefficient of recycling difficulty, and vice versa.

These results indicate that the high intensity of the government incentives could benefit the improvement in recycling express packaging, while the government needs to bear a high cost of the strong incentives. In addition, government regulation is even more necessary in the situation that express packaging is difficult to recycle.

3.3.3 The stability analysis considering the strong consumer's environmental awareness

Consumers are important factors that affect the recycling process, especially consumers with significant environmental awareness (Rhein & Schmid, 2020). Based on the analysis conclusions in the previous section, we set $\lambda > 0$ to analyze the local asymptotic stability of the evolutionary game model. Besides, to simplify the analysis, we only discuss the case $R_1 - cT_1^2 < R_2 - cT_2^2$. The analysis of the local asymptotic stability of each equilibrium point is also shown in Table 3.

It can be found from Table 3 that when considering the consumer's environmental awareness, there are three saddle points, which are $(0, 0)$, $(1, 0)$ and $(1, 1)$. That means the equilibrium point can reach a stable state when the condition $R_1 - (1 - \lambda)cT_1^2 > R_2 - (1 - \lambda)cT_2^2$ is satisfied. Therefore, compared to the results considering the worst consumers' environmental awareness, participation of consumers with strong environmental awareness in express package recycling will improve the achievement of the optimal state of actively recycling by recyclers.

4 Numerical simulation analysis

In this section, we present some numerical simulation analysis with the help of MATLAB software. Then we carry out sensitivity analysis of key parameters, aiming to investigate their influence on the evolutionary path of strategies of the government and the recycler in the express packaging recycling industry intuitively.

4.1 Simulation design

To simulate the evolutionary game analyzed in Sect. 3, the replicated dynamic Eqs. (9) and (10) can be discretized to trace the asymptotically stable track as follows:

$$\begin{cases} L(x) = \frac{dx}{dt} \approx x(t)(1 - x(t))(U_{11} - U_{12}) \\ L(y) = \frac{dy}{dt} \approx y(t)(1 - y(t))(U_{21} - U_{22}) \end{cases} \quad (12)$$

Based on the replicated dynamic system above, and following the relevant literature Chen & Hu (2019), the relevant parameters are set as $W_1 = 200$, $W_2 = 100$, $C_g = 12$, $k = 150$, $c = 30$, $T_0 = 0.5$, $T_1 = 0.7$, $T_2 = 0.3$, $R_1 = 100$, $R_2 = 80$. Thus, the evolutionary game of recycling express packaging can be simulated to perform the evolutionary path of the system by using function `ode45` in MATLAB.

4.2 The evolutionary path of the game system

4.2.1 The evolutionary path considering the worst consumers' environmental awareness

When the worst consumer's environmental awareness is considered, that is $\lambda = 0$, there are two possible cases in the evolutionary game model as analyzed in sub-Sect. 3.2. Here, the two cases are simulated as follows.

(1) The evolutionary path of Case 1

According to sub-Sect. 3.3.2, in case 1, the condition $R_1 - cT_1^2 > R_2 - cT_2^2$ is satisfied. Meanwhile, the parameters x_0 and y_0 represented the initial willingness of the government to supervise and recyclers to actively recycle, respectively. The results are shown in Fig. 2.

As can be seen from Fig. 2, no matter what the initial willingness of the government to adopt the strategy of "supervise" or the recycler adopting the strategy of "actively recycle", the ideal state of {not supervise, actively recycle} will always be achieved. Thus, the recycler is willing to take the initiative to actively recycle, and the government's supervision is not necessary. And the stronger the initiatives are, the faster the ideal stable state will be realized. However, in practice, in the early stage of the express packaging recycling industry, the huge investment makes it hard to carry out the recycling business, which decreases the enthusiasm of the recycler. Therefore, it is difficult for the express packaging recycling industry to achieve an ideal stable state.

(2) The evolutionary path of Case 2

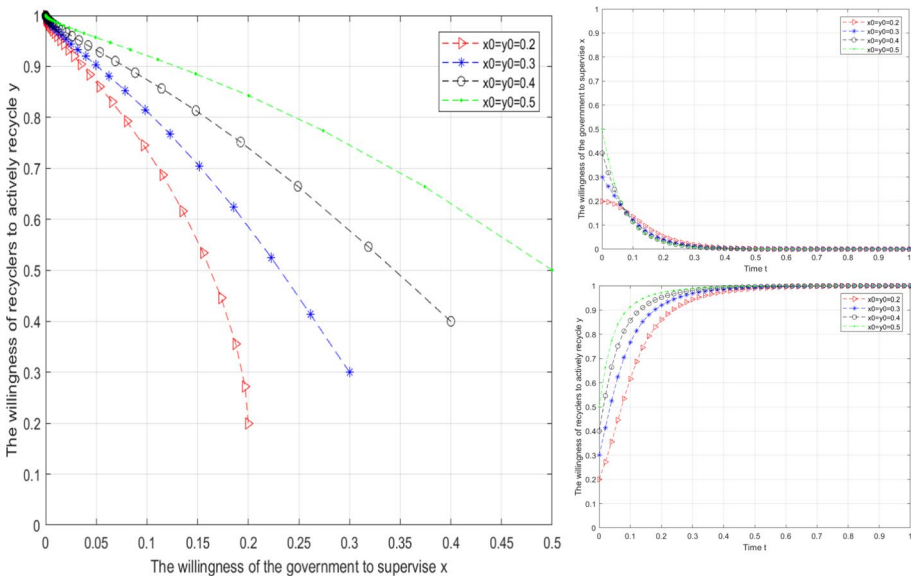


Fig. 2 The evolution path of Case 1 ($\lambda = 0$)

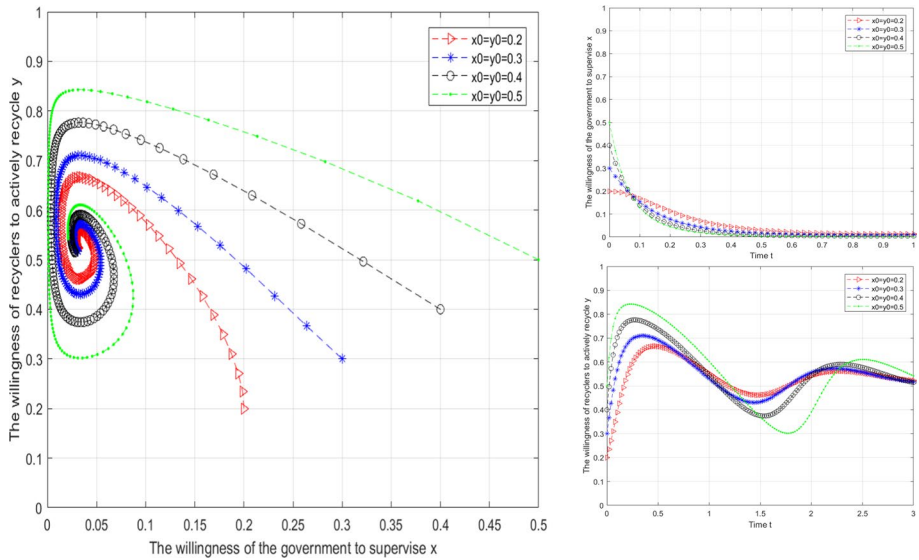


Fig. 3 The evolution path of Case 2 ($\lambda = 0$)

In Case 2, the condition $R_1 - cT_1^2 < R_2 - cT_2^2$ needed to be satisfied. So, we set $R_1 = 90$, and other parameters are the same as these in Case 1. The results are shown in Fig. 3.

As can be seen from Fig. 3, the evolution path of the recyclers’ strategy selection is fluctuant in Case 2, and the stable state cannot be achieved in a short time. What’s more, in the final state of the evolutionary game system, the willingness of the government to adopt the strategy of “supervise” is low, so does the willingness of the recycler to adopt the strategy of “actively recycle”. Even if the initial willingness of the government to supervise is improved, the ideal stable evolutionary equilibrium cannot be realized still, which will make the strategy selection of the recycler fluctuant much more on the contrary.

Compared to Case 1, the conditions in Case 2 are in line with the actual situation better, where the net profit the recycler will obtain from the strategy of “actively recycle” is less than the strategy of “negatively recycle”. It can be seen that the unsatisfying benefits reduce the recyclers’ willingness to recycle express packaging. The incentives from the government could reverse the situation, while it cannot retain all the recyclers. Thereby, some of the recyclers are squeezed out of the recycling. Hence, in the scenario with the worst consumers’ environmental awareness, the government incentives can promote the express packaging recycling industry, but the effect is limited.

4.2.2 The evolutionary path considering the strong consumers’ environmental awareness

When the strong consumer’s environmental awareness is considered, which means $\lambda > 0$. Hence, we set $\lambda = 0.1$ and $\lambda = 0.3$ to describe the high and low environmental awareness of consumers, respectively. The results are shown in Fig. 4.

By observing Fig. 4, it can be found that the participation of consumers with strong environmental awareness has a significant impact on improving the recycler’s willingness to recycle the express packaging actively. Therefore, to improve the efficiency of the

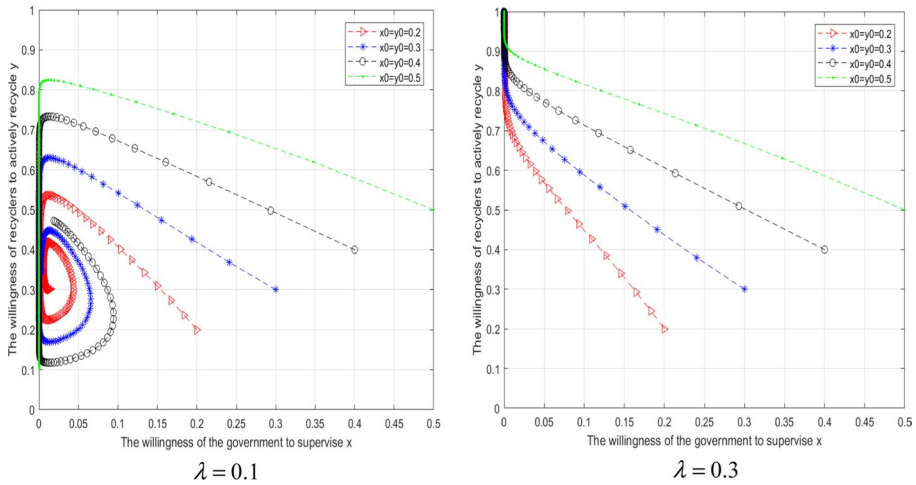


Fig. 4 The evolution path of the game system

express packaging recycling system, it is crucial to strengthen consumers’ environmental awareness and encourage them to participate in it appropriately actively. Meanwhile, the simulation results also indicate that the low consumers’ environmental awareness cannot reduce the recycling difficulty of the recycler significantly, in which situation the participation of the consumers with environmental awareness is not helpful to improve the express packaging recycling industry significantly. With the improvement of consumers’ environmental awareness, the recycling difficulty of recyclers will be reduced significantly, and the willingness of recyclers will increase significantly. And the stronger the consumers’ environmental awareness is, the recyclers are more willing to recycle the express packaging actively, and the system converges to the ideal stable state faster. Finally, the ideal stable state that recyclers are willing to recycle the express packaging actively when the government does not have to supervise will be realized. Hence, the consumers’ strong environmental awareness is a basis for recycling express packaging.

4.3 Sensitivity analysis

Aiming to further explore the impacts of the key driving factors on the stable strategy selection of the recycler in the game system of the express packaging recycling industry, we carry out some sensitivity analysis by numerical simulations as follows. The simulation results are shown in Fig. 5.

4.3.1 The impact of the intensity of the reward and punishment

To figure out the impact of the intensity of the reward and punishment on the strategy selection of the recycler, the parameter k is set as 0, 100, 200, and 300, respectively, with other parameters remaining unchanged. It can be found from Fig. 5 that in the

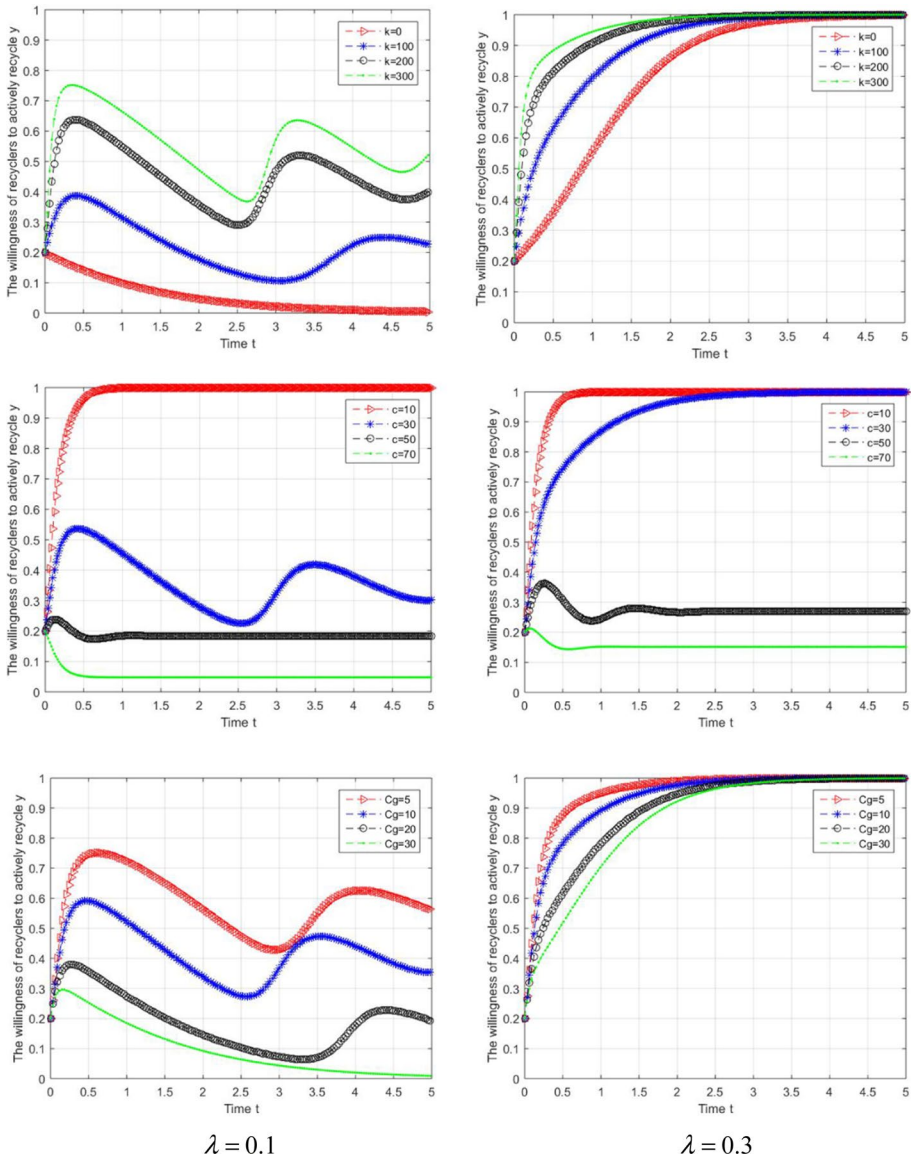


Fig. 5 The evolution path with the key driving factors

absence of significant consumers' environmental awareness, it is difficult for the recycler to recycle the express packaging on its initiative by their self-consciousness without the reward or punishment carried out by the government. Even if the willingness of recyclers to recycle the express packaging increases with the increasing intensity of reward and punishment, it still flattens out and declines eventually, which makes the ideal stable state hardly achieve.

In contrast, the situation is different with the participation of consumers with strong environmental awareness. At this time, the willingness of the recycler to choose the strategy of “actively recycle” will keep rising rapidly. What’s more, the rising speed is accelerated with the enhancement of rewards and punishments. Therefore, the intensity of reward and punishment affects the income of recyclers directly. It is necessary for the government to design and implement a reasonable reward and punishment mechanism to improve the express packaging recycling industry. But we can’t rely on the mechanism only by mobilizing consumers’ environmental awareness and participation enthusiasm can we get twice the result with half the effort.

4.3.2 The impact of the recycling difficulty

To figure out the impact of the recycling difficulty on the strategy selection of the recycler, the parameter c is set as 10, 30, 50, and 70, respectively, with other parameters remaining unchanged. As illustrated in Fig. 5, the difficulty of recycling always has a great inhibition on the enthusiasm of recycling whether the consumers’ environmental awareness is strong or not. It is worth noting that the inhibition is less in the situation that the consumers have strong environmental awareness. To be specific, when the consumers’ environmental awareness is strong, the recycling difficulty is reduced significantly. As a result, it is harder for the increasing recycling difficulty to drive the recycler to abandon the strategy of “actively recycle”, while it is much easier when the consumers’ environmental awareness is weak. Therefore, the consumers’ strong environmental awareness helps the recycler save the cost of recycling by reducing the difficulty of recycling, which plays an active role in improving the express packaging recycling industry.

4.3.3 The impact of the cost of supervision

To explore the impact of the cost of supervision on the strategy selection of the recycler, the parameter C_g is set as 5, 10, 20, and 30, respectively, with other parameters remaining unchanged. The cost of the supervision affects the strategy selection of the government directly, and then has impacts on the strategy selection of the recycler. As can be found from Fig. 5, when the consumers’ environmental awareness is weak, the recyclers’ enthusiasm is fluctuated, making it difficult to end up with the stable strategy of “actively recycle”, unless the cost of supervision is extremely expensive. The increasing cost of supervision, which means strict regulations, could smooth its fluctuations, but drive it to converge to abandon the strategy of “actively recycle”. On the other hand, when the consumers’ environmental awareness is strong, no matter what the cost of government supervision is, the willingness of the recycler to choose the strategy of “actively recycle” always reaches the ideal stable state of 100% quickly. Meanwhile, the smaller the cost is, the fast the ideal strategy selection will be achieved.

5 Discussion of the results

The implementation of the express packaging recycling industry is a process of multi-party coordination involving multiple stakeholders, including the government and the recycler. The key to the improvement of the express packaging recycling industry is to find an

appropriate intensity of rewards and punishments to satisfy the interests of multiple stakeholders involved and find the optimal solution to improve the willingness of the recycler to recycle express packaging actively. Chen et al. (2019) found out in their research on waste recycling that the government's reward and punishment mechanism alone could not effectively motivate recyclers, but they ignored the influence from consumers. Then, Wang et al. (2020) take the factors of consumers into the picture to develop an evolutionary game model to analyze the e-waste recycling issues, but the impact of consumers' environmental awareness has not been considered. To fill this gap, this paper introduces the consumers' environmental awareness into the framework to explore the solutions to promote the express packaging recycling industry. Based on that, this paper develops an evolutionary game model of the recycler and the government to discuss the coordination of the government incentives and the recyclers' behavior in the express packaging recycling industry considering the consumers' environmental awareness. In addition, the presented studies also analyze the effects of relevant factors through sensitivity analysis, such as the intensity of reward and punishment, recycling difficulty, and cost of supervision.

According to the results obtained from the stability analysis and the numerical simulation, the recycling express packaging activities can achieve their ideal state in the scenario that the recycler could obtain satisfying benefits, or in the scenario that the consumers have strong environmental awareness. In fact, the second scenario is more consistent with the reality that the recyclers have difficulty in making satisfied profits from recycling express packaging (Yuan et al., 2020). Moreover, consumers' environmental awareness still needs to be further improved (Zeng et al., 2019). Hence, the finding indicates that it is necessary for the government to conduct these incentives to improve the situation in the recycling express packaging industry.

The government incentives can increase the recycler's willingness to recycle express packaging when they are unable to obtain satisfying benefits from recycling. However, the government incentives work effectively only if consumers have strong environmental awareness. The result is in line with the previous research (Cao & Liu, 2019; Van Birgelen et al., 2009; Wang et al., 2021). Furthermore, the finding confirms the role of consumers' environmental awareness in the mechanism of government incentives including reward and punishment. To improve the recycling express packaging industry, all of the parties involved should enhance their belief in sustainable production and consumption. The government and the manufacturers, recyclers should take measures to promote the consumers' awareness on conducting sustainable consumptions. And the government incentives have to match the consumers' environmental awareness to fulfill their encouraging effects.

In addition, the recycler's willingness to recycle express packaging may be harmed by the recycling difficulty, which can be smoothed by the consumers' environmental-friendly consumption and the government incentives including the reward and the punishment. Furthermore, the enhancement in the intensity of the government incentives could improve the willingness of recyclers to recycle express packaging actively, while the excessively high cost of supervision may make the government incentives unsustainable. Therefore, it is worth noting that in addition to enhancing consumers' environmental awareness, the improvement of the express packaging recycling industry requires not only the government to design and implement incentives with reasonable intensity, but also reduce the supervision cost.

6 Conclusions and implications

6.1 Conclusions

In this paper, we develop an evolutionary game model with worst or strong consumers' environmental awareness to discuss how the government incentives and recyclers' strategy coordinate in the recycling express packaging industry. Then we investigated the dynamically evolutionary path of their decision-making by numerical simulation. Finally, we examine the driving factors on the coordination through sensitivity analysis. The main conclusions are the following:

1. With the worst consumers' environmental awareness, the implementation of reward and punishment mechanism supervised by the government cannot restrict the decision-making of recyclers effectively and have no obvious impact on the enthusiasm of the recycler to recycle the express packaging. The evolution path of the recycler is fluctuating and cannot achieve a stable state in a short period.
2. The strong consumers' environmental awareness is incorporated into the framework, a certain level of environmental awareness (0.3) will effectively solve the problem that the strategy of recycler cannot end up with the stable ideal state of "actively recycle" only relying on the reward and punishment mechanism implemented by the government.
3. The influence of government rewards and punishments, recycling difficulty coefficient and other parameters will be quite different with or without consumers with strong environmental awareness participating. When the consumers' environmental awareness is strong, the recycler's decision-making can evolve in the direction of positive recycling.

6.2 Implications

According to the conclusions above, here are some implications proposed as follows:

First, the government and the recyclers need to take reasonable measures to improve consumers' recycling enthusiasm. For instance, financial incentives, such as discounted trade-in prices, can be adopted to attract consumers participation. And convenient recycling channels should be set up, such as the community recycling station, a smooth recycling process, etc. These arrangements could provide the consumers with various ways to recycle the express packaging effectively, which would be helpful to improving the participation of consumers by reducing their time and efforts spent on it.

Second, as the regulator, the government should adjust the regulatory policies and the mechanism of reward and punishment for the express packaging recycling industry to fit the changing environment. Meanwhile, the government should improve the public supervision system and establish a convenient, safe, and efficient reporting mechanism to make sure the recycler works as promised.

Third, the scientific research institutions should speed up scientific and technological innovation to improve the recycling value of the express packaging and reduce environmental damage. At the same time, the relevant industry departments could formulate industry standards to promote the application of green packaging materials and technologies, such as the e-commerce green packaging standards, the plans of express packaging recycling and reuse, and so on.

6.3 Limitations and future research

It should be noted that the present study still has some limitations. First, the consumers are taken into the model as exogenous influencing factors, and it is assumed that consumers' awareness of environmental protection will affect the recycling difficulty coefficient of recyclers. In fact, there are complex interactions among the participants in express packaging recycling. In future research, it can be treated as one of the participants in the game model, so the interaction among the multi-players may be investigated more accurately to the reality. Furthermore, the environmental awareness of consumers will also affect the market demand function and thus affect the operating profit of recyclers. Hence, introducing consumers into the evolutionary game model and establishing a three-party evolutionary game model consisting of the government, the recyclers, and the consumers are the direction worth studying in the future. Second, express packaging recycling is a complex resource recycling activity that is susceptible to many factors, including the foreseen and the unforeseen factors. The exploration on express package recycling in this paper took the foreseen factors into account while the unforeseen factors, such as the stochastic shocks arising from unexpected events, are omitted. Actually, since the participants in recycling are bounded rational, its behaviors may be affected by the stochastic shocks. In the future, employing a stochastic evolutionary game model to capture the strategies of recycling resources is worthy to explore. Third, even though this paper discusses the issues of express packaging recycling considering that the participants are bounded rational, it still takes the expected profits as the decision-making basis. Actually, participants often have different perceptions of the gains and losses, which will directly determine the strategy adaptation. In the future, more effective decision functions need to be designed such as applying prospect theory to incorporate participants' risk attitudes toward gains and losses, to capture participants' behaviors accurately.

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