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The Strategy Selection of Government Supervision and Closed-loop Supply Chain's Environmental Investment: An Evolutionary Game Approach

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Abstract

Considering some closed-loop supply chains (CLSC) gives little money to improve its operation system environmentally, an evolutionary game model of the strategy selection of the government supervision and the CLSC's environmental investment is set up. The evolutionary stable strategy (ESS) is explored in six different circumstances, and some numerical simulation experiments are made to discover the impact of the decision parameters' values and the two initial population rates on the ESS. The results show: (1) When there is high income from the investment, CLSCs will invest money to improve its environmental operation ability no matter whether the governments supervise or not. (2) When income from the investment is not very large, the governments need to increase the punishment and reward values, and implement some incentive policies to improve the development of environmental techniques in order to decrease the investment cost for CLSCs.

Keywords: Government supervision; Social; Closed-loop supply chain; Environmental investment; Social policies; Evolutionary stable strategy; Evolutionary game

Introduction

With the rapid development of technology and productivity, the speed of product development, production, use and renewal is becoming faster and faster, the quantity of discarded products is becoming more and more, and the problems of resource consumption and environmental deterioration are becoming increasingly prominent, especially in China, where the economy is in a period of rapid growth. In order to make full use of the residual value of the used products and reduce their harm to the environment, many countries in the world have issued relevant policies, laws and regulations to strengthen the guidance and regulation of sustainable development of enterprises, and to promote the development of closed-loop supply chains (CLSC) [1].

Governments usually adopt two kinds of policies to guide the behaviours of closed-loop supply chains, one is the reward-penalty policy and the other is the subsidy policy according to the collection quantity. The reward-penalty policy generally sets a specific value, a manufacturer will receive some reward from the government when its collection rate of the discarded product is above the specific value, and the manufacturer will pay some penalty to the government when its collection rate is below the specific value. The reward and penalty policy should be designed carefully because which directly affects the economic and ecological performance of a CLSC with different characteristics, such as the collection process run by the manufacturer or the retailer separately [2], the collection process run by the manufacturer, the retailer and the third party simultaneously [3], the collection process run by two competing manufacturers [4].

Considering the reward-penalty policy mainly affecting the enterprises behavior, the governments introduce some recovery subsidy policies which could mobilize consumers to participate in the closed-loop supply chain. A subsidy policy is the mechanism that the government endows allowance to recycling enterprises based on the amount of their recovery [5]. Although the subsidies are directly awarded to the recycling corporations according to their collection quantity by the government, the corporations can introduce different market activities according to their received subsidies, such as old-for-new subsidy or second-hand cash coupon, which will increase consumers' enthusiasm to participate in closed-loop supply chain. So the subsidy policies can be taken as a method to effect consumers' behavior. The recycling fees and government subsidy fees may curtail the consumption of new products and encourage consumers to recycle the end-of-life (EOL) products so as to influence the profit of the forward and reverse supply chain [6]. By offering a discount or a direct fee in exchange for bringing back EOL products, the corporations in a supply chain can increase customers' willingness to return used products and finally improve the sustainable consumption, so the governments can play its role in promoting the sustainability of a supply chain through denoting different incentives to the corporations [7]. The impact of the recycling subsidy policy on the recycling and reuse industry also is influenced by other factors, such as the manufacturer's innovation ability, consumer environmental awareness and sensitivity to the subsidy [8]. Sometimes, the recycling parties in a closed-loop supply chain may collect the EOL products in an alliance, the subsidies should be considered in a different way to obtain the optimal environment performance and economic profits [9,10].

These two policies are designed to improve the recollecting quantity, but which don't think about the outputting pollution produced by the remanufacturing processes. In reality, especially in today's China, many CLSC enterprises don't have the disassembly certification, effective environmental protection equipment or technology. These enterprises may cause very adverse results, such as lower resource utilization and secondary pollution, in the processes of waste recycling, disassembly and remanufacturing. Aiming to drive these enterprises to spend more money to improve its environmental processing ability, this paper uses

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the evolutionary game method to explore the evolution paths of the government supervision and the CLSC environmental investments under the consideration of both economic and environmental targets, analyzes the influences of the strength of government supervision, the supervise cost, the environment investment cost and profit on the strategy choices of the government and the supply chain, hopes to obtain some valuable theories to help the government and the CLSC to do correct decision making and finally to improve the environment.

The paper is organized as follows. In Section 2, we review the related literatures on closed-loop supply chain and the government policies to CLSCs. In Section 3, we give the problem description and build the evolutionary game models. In Section 4, we analyze the evolutionary equilibrium strategies for both parties under different scenarios. In Section 5, some numerical simulations illustrate the evolutionary paths of the two parties under different conditions. Finally, in Section 6, conclusions are presented.

Literature Review

Since the early 21st century, closed-loop supply chain has widely obtained the researching interest of academic and business participants, and there are so many literatures on the field of closed-loop supply chain. In this section, we give a review on three fields of the literatures that are closely related to our study, i.e., the design and optimization for CLSC's network considering environmental factors, the coordination of CLSCs' operation to achieve better environmental output, the government policies on CLSCs' decisions for better environmental output.

The design and optimization for CLSC networks considering environmental factors

The network design and optimization plays a great role in the CLSC operation processes and its performance. In the past, minimizing the total cost or maximizing the profit was the main objective of the supply chain network planning, but now the environmental impacts of their products and operations, the health and safety of their employees and the whole society are played very important roles in the decision processes. The network optimization of a CLSC is to minimize its total costs and total environmental impacts while to maximize its social benefits [1], or to minimize its total cost, waste, carbon dioxide [11,12], hazardous residual and risks[9].

The attributes of the customer are also important impact on the CLSC network design. The uncertainty of the quality and return rate of the used products is needed to consider in the process of designing the CLSC network. The uncertain quality status of the return product affects a CLSC network design [13]. The uncertainties of return rates, revenues, costs and the quality of returns impact the network structure and profit of a CLSC [14]. The demand for the recycled product also changes the network structure of a CSLC [15]. The quantity of new product demand, the quantity of used product demand, and the facility opening cost are important factors which should be considered in a CLSC network optimization [16].

The design and optimization of a CLSC network contains the determination of locations, numbers and capacities of network facilities as well as the material flow through the network. The differences among the members of the CLSC are the other important factors to be considered. Such as the environmental operating abilities of different suppliers and distribution centers [17], the disruption and carbon emission differences of the suppliers [18].

The coordination of CLSC's operation to achieve better environmental output

When the structure of a CLSC is fixed, there also have some measures that can improve the whole CLSC's performance including environmentally friendly output and economic profit. These measures could be divided into three categories, named as the coordination among the vertical members in the CLSC, the coordination among the horizontal members in the CLSC and the coordination between remanufacturing product and new product respectively. The coordination among the vertical members refers to the decision interaction happening among the upstream and the downstream of the CLSC. Panda et al. [19] analyzed the effects of corporate social responsibility (CSR) and explores channel coordination in a socially responsible manufacturer-retailer CLSC by considering both profit and social responsibility through product recycling. Zhu et al. [20] studied the coordination contracts among the manufacturers, retailers, and network recycling platforms in a CLSC facing customers' bargain behavior. Xu and Wang [21] explored the decision strategy and profit distribution of a CLSC compromised by a manufacturer supplying new products to a retailer, the retailer recalling/remanufacturing used product and selling the remanufacturing and new product to customers, and the customers possessing low-carbon and remanufactured preference.

The coordination among the horizontal members refers to the decision interaction happening among the competitive members positioning in the same level of a CSLC. Gao et al. [22] investigated a coordination mechanism for a CLSC, in which the manufacturer used its direct channel and indirect channel to sell products and entrusted the retailer to collect the used products, to achieve environmental friendly operating system. Zou et al. [23] examined a coordination mechanism in a CLSC including one manufacturer and two competitive retailers, and gave the revenue sharing contract which could coordinating the wholesale prices, the retailing prices and the recycling prices to achieve the optimal environmental results. Xie et al. [24] studied a coordination mechanism between the online channel and the offline channel of a CLSC to improve the recycling productivity. Taleizadeh et al. [25] compared and analyzed the equilibrium solutions of two kinds of CLSC structure, and deduced the optimal prices and collection efforts under different coordination contracts.

The coordination between new products and remanufactured products is inevitable to be obtained great attention in CLSCs. Abbey et al. [26] considered the difference between new product and remanufactured product and designed a coordination mechanism which could increase the efficiency of the CLSC by 25%. Bhattacharya et al. [27] studied the selling prices of new products and remanufactured products while the recollection price was optimized according to the used product quality and remanufacturing cost.

And more researches on CLSCs could be found in these reviews [28,29].

The government policies on CLSC's decisions for better environment output

The government plays an important role in the development of the CLSC. There are lots of literatures on government policies and their effects. Ma et al. [5] analyzed the changes of the decision making in a CLSC after the government funded subsidies for customer to buy new product and recycle used product. Wang et al. [30] studied the selling channel choice decision of a remanufacturer who could receive the government subsidy to incentive its remanufacturing activities. Heydari et al. [7] explored the coordination problem in a reverse supply chain considering the tax exemption and subsidy from the government according to the supply chain members' contribution on recollecting used product, and Jena et al. [31] also studied the effect of the government subsidy based on the recollecting quantity. Dai et al. [32] and Zhang et al. [4] analyzed the influence of the adjustment speed of carbon quota subsidy and carbon tax on the carbon emission of CLSCs.

From the above literatures, there is a potential assumption which is that the ability of a CLSC member is predefined and fixed. Based on this assumption, a lot of methods are developed to optimize the CLSC network, and the wholesale prices, the retail prices and the recycle prices are optimized. But in order to improve the environment, the supply chains need to increase its recycling effectiveness and decrease its output of hazardous substances by invest advanced equipments and techniques. CLSCs are interests-driven agents, invest or not invest in upgrading their environmental ability is decided by the profit of the strategy selection, so the governments can guide the CLSCs' strategy selection by carrying out some degree of supervision with penalty and reward according to the different market payoffs.

Problem Description and Game Model

Problem description

The CLSCs collect the discarded products from the market and then remanufacture and sale them again. Because the CLSCs want to obtain the maximum profit from these businesses, they don't have the will to invest much money to set up advanced machines or technologies which can improve the recycling efficiency and reduce the waste discharge. At present China, the CLSCs' existence is enhancing the reuse of the discarded products, but at the same time it is aggravating the environmental pollution [33]. Overall, however, under the current technological level and market conditions in China, the existence of closed-loop supply chain still has positive social and environmental effects [34,35]. As a result, the government's supervision and regulation measures are not very complete and severe because of these positive characteristics of CLSCs. But in order to impels the CLSCs gradually evolve to an ideal environmental operating status and play a better role in resource reuse and environmental protection, the government needs to take some powerful measures to supervise the CLSCs, and promote its investment in environmental protection, and enhance its technological level and pollution disposal capability in the process of recycling.

The CLSCs and the government sections constitute a game. The CLSCs have two pure strategies: invest or not invest, and the government sections also have two pure strategies: supervise or not supervise. Assuming that the government sections supervise and investigate the CLSCs by a certain random proportion *α*, if a government section finds that a CLSC has not invested in the environmental protection system, it will punish a fine of *P* on the CLSC. If a government section finds that a CLSC has invested in the environmental protection system, it will give a reward *A* to the CLSC. In the situation, the governments will pay a cost C_g for the implementation of regulatory activities. Assuming that the CLSCs invest the environmental protection system by a certain random proportion *β,* the CLSC who chooses the strategy invest will use the investment C_i and create the pollution effect *h* and obtain economic profit E_1, while the CLSC who chooses the strategy not invest will create the pollution effect *H* and obtain economic profit E_2. Both of the two kinds CLSCs could create resource reusing social benefit *R*.

In order to limit the research's scope, the following three assumptions and a definition are given:

1. The pollution effect of a CLSC adopting invest strategy is lower than that of a CLSC adopting not invest strategy, that means h<H.
2. The economic profit of a CLSC adopting invest strategy is bigger than that of a CLSC adopting not invest strategy, that means E1>E2.
3. All of the parameters of this game is bigger than 0.
4. Name E1-Ci as the environmental protection profit (EPP) of the supply chain, E2 as the normal profit (NP) of the supply chain, and E=E1-Ci-E2 as the environmental protection premium profit (EPPP) of the supply chain.

Game model

Based on the idea of the Eagle-pigeon game framework, the game revenue matrix of government supervision and closed-loop supply chain environmental investment strategy is established as Table 1.

Profit analysis for the governments: When the government chooses the regulatory measure, its profit is:

$$U_{g1} = \beta\left(R - C_g - h - A\right) + \left(1-\beta\right)\left(R - C_g - H + P\right) \tag{1}$$

When the government does not choose the regulatory measure, its profit is:

$$U_{g2} = \beta\left(R - h\right) + \left(1-\beta\right)\left(R - H\right) \tag{2}$$

The average profit of the government is:

$$\overline{U}_g = \alpha U_{g1} + \left(1-\alpha\right)U_{g2} \tag{3}$$

Thus, the replication dynamic equation for the government who chooses the regulatory strategy is:

$$\frac{d\alpha}{dt} = \alpha\left[U_{g1} - \overline{U}_g\right] = \alpha\left(1-\alpha\right)\left[P - C_g - \beta\left(A+P\right)\right] \tag{4}$$

Profit analysis for the CLSC

When the CLSC chooses the environmental investment measure, its profit is:

$$U_{c1} = \alpha\left(E_1 - C_i + A\right) + \left(1-\alpha\right)\left(E_1 - C_i\right) \tag{5}$$

When the CLSC does not choose the environmental investment measure, its profit is:

$$U_{c2} = \alpha\left(E_2 - P\right) + \left(1-\alpha\right)E_2 \tag{6}$$

The average profit of the CLSC is:

$$\overline{U}_c = \beta U_{c1} + \left(1-\beta\right)U_{c2} \tag{7}$$

Thus, the replication dynamic equation for the CLSC who chooses the environmental investment strategy is:

$$\frac{d\beta}{dt} = \beta\left[U_{c1} - \overline{U}_c\right] = \beta\left(1-\beta\right)\left[\alpha\left(A+P\right) + E\right] \tag{8}$$

Analysis on the evolution of stable points: By solving the simultaneous equations which is formed by the replication dynamic equation of the government supervision strategy and that of the CLSC investment strategy, the five local equilibrium points are achieved: $O(0,0), A(1,0), B(0,1), C(1,1)$ and $D\left(\frac{-E}{A+P}, \frac{P-C_g}{A+P}\right)$, where the equilibrium point D only exists when $0 \le \frac{-E}{A+P} \le 1$ and $0 \le \frac{P-C_g}{A+P} \le 1$ are true simultaneously.

The stability of these equilibrium points can be obtained based on the stability of the problem's Jacobian matrix [35]. The Jacobian matrix J of the problem is obtained by partial derivation of the replication dynamic equations for α andβ respectively:

$$J = \begin{bmatrix} (1-2\alpha)\left[P - C_g - \beta(A+P)\right] & \beta(1-\beta)(A+P) \\ -\alpha(1-\alpha)(A+P) & (1-2\beta)\left[\alpha(A+P)+E\right] \end{bmatrix} \quad (9)$$

Evolution Table Strategies Analysis

P>C_g, E+A+P<0

These two expressions show the scenario of low supervision cost and low environmental protection premium profit (LSC and LEPPP) because that the government supervision cost is lower than the penalty cost imposed to the CLSC who adopt not invest strategy and the sum of the EPPP pluses the government's reward and penalty is lower than zero. LEPPP means the extra profit from the invest strategy is less than the investment cost, even considering the reward and penalty from the government. In this scenario, there are four equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$. The stability analysis is shown in Table 2.

From Table 2, The equilibrium stable point (ESS) is A(1,0) for the two game parties in the LSC and LEPPP scenario, the ESS represents that the government will certainly choose the supervise strategy while the CLSC will certainly choose the not invest strategy. In this scenario, because the supervision cost is very low and the penalty fee is very high, the governments are very willing to implement the supervise strategy to monitor all of the CLSCs' operation. However, the high environmental investment cost Ci leads to the CLSC negative EPPP, even considering the government's penalty and reward. As independent economic agents, the CLSCs will naturally choose not to invest in environmental protection measures.

P>C_g, 0>E+A+P<A+P

These two expressions show the scenario of low supervision cost and medium environmental protection premium profit (LSC and MEPPP) because that the government supervision cost is lower than the penalty cost imposed to the CLSC who adopt not invest strategy and the sum of the EPPP pluses the government's reward and penalty is higher than zero but lower than the sum of the government's reward and penalty. MEPPP means the extra profit from the invest strategy is less than the investment cost, but the CLSC will obtain positive profit when considering the reward and penalty from the government. In this scenario, there are five equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$ and $D\left(\frac{-E}{A+P}, \frac{P-C_g}{A+P}\right)$. The stability analysis of these five equilibrium points is shown in Table 3.

From Table 3, there is no any ESS point for the two game parties in the LSC and MEPPP scenario, and both the governments and the CLSCs will choose the mixed strategies. In this scenario, when the governments choose a higher proportion of regulatory strategies because of the low supervision cost, the members of the closed-loop supply chains who choose to adopt environmental investment to avoid the penalty from the government will increase. However, with the increase of the proportion of the CLSCs who choose invest strategy, because the government needs to pay the supervision cost and give more reward to the supply chains that adopt the environmental investment, the government will gradually reduce the proportion of supervision. And then, due to the weakening of government supervision, the CLSCs are uncertain that they will achieve the government reward to compensate for the negative environmental protection premium profit, which will increase the proportion of the CLSCs choosing the not invest strategy. In this way, the result of the evolutionary game is that the government and the closed-loop supply chains will choose the mixed strategies.

P>C_g, E>0

These two expressions show the scenario of low supervision cost and high environmental protection premium profit (LSC and HEPPP) because that the government supervision cost is lower than the penalty cost imposed to the CLSC who adopt not invest strategy and the sum of the EPPP pluses the government's reward and penalty is lower than zero. HEPPP means the extra profit from the invest strategy, even which doesn't include the reward and penalty from the government, is bigger than the investment cost. In this scenario, there are four equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$. The stability analysis of these four equilibrium points is shown in Table 4.

From Table 4, The equilibrium stable point (ESS) is B(0,1) for the two game parties in the LSC and HEPPP scenario, the ESS represents that the governments will certainly choose the not supervise strategy while the CLSCs will certainly choose the invest strategy. In this scenario, because environmental investment can achieve positive environmental premium profit, whether the governments reward or

Government	CLSC	
	Invest β	Not invest 1-β
Supervise α	R-h-Cg-A, E_1-C_i+A	R-H-Cg+P, E_2-P
Not supervise 1-α	R-h, E_1-C_i	R-H, E_2

Table 1: The payoff matrix of government supervision and CLSC environmental investment.

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$E(P-C_g)$	-	$A+C_g+E$	-	Saddle point
A	$(P-C_g)(-E-A-P)$	+	$A+C\ \ +E$	-	ESS
B	$E(C_g+A)$	-	$-E-C_g-A$	+	Saddle point
C	$(C_g+A)(-E-A-P)$	+		+	Unstable

Table 2: The stability analysis under the LSC and LEPP scenario.

not, the CLSCs will spontaneously choose environmental investment strategy, which can improve their income and reduce the harm created by their operations to the environment. Because the government's reward likes to place embroidery upon silk for the CLSC's decision on environmental protection investment, whether the governments supervise or not will not affect the strategy of the CLSCs, which will reduce the enthusiasm of the governments to supervise the CLSCs. Meanwhile, without supervision actions will save the cost of government operation and further promote the governments to take not supervise strategy.

$P<C_g$, $E+A+P<0$

These two expressions show the scenario of high supervision cost and low environmental protection premium profit (HSC and LEPPP) because that the government supervision cost is higher than the penalty cost imposed to the CLSC who adopt not invest strategy and the EPPP is positive. LEPPP means the extra profit from the invest strategy is less than the investment cost, even considering the reward and penalty from the government. In this scenario, there are four equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$. The stability analysis of these four equilibrium points is shown in Table 5.

From Table 5, the equilibrium stable point (ESS) is O(0,0) for the two game parties in the LSC and HEPPP scenario, the ESS represents that the governments will certainly choose the not supervise strategy while the CLSCs will certainly choose the not invest strategy. In this scenario, because the supervision cost is very high while the penalty which the government punishes the closed-loop supply chain adopting not invest is too low, in the long-term evolution process, the governments tend to the not supervise strategy. Because the EPPP is negative, and even the sum of the EPPP and the penalty and reward from the government's supervision is negative, the CLSCs have to choose the not invest strategy in order to maximize its economic profit.

$P<Cg$, $0<E+A+P<A+P$

These two expressions show the scenario of high supervision cost and medium environmental protection premium profit (HSC and MEPPP) because that the government supervision cost is higher than the penalty cost imposed to the CLSC who adopt not invest strategy and the sum of the EPPP pluses the government's reward and penalty is higher than zero but lower than the sum of the government's reward and penalty. MEPPP means the extra profit from the invest strategy is less than the investment cost, but the CLSC will obtain positive profit when considering the reward and penalty from the government. In this scenario, there are four equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$. The stability analysis of these four equilibrium points is shown in Table 6.

From Table 6, the equilibrium stable point (ESS) is O(0,0) for the two game parties in the HSC and MEPPP scenario, the ESS represents that the governments will certainly choose the not supervise strategy while the CLSCs will certainly choose the not invest strategy. In this scenario, the ESS is the same as that of the scenario of HSC and LEPPP. The reason of the government choosing the not supervise strategy is the same as the scenario of HSC and LEPPP, but there are some differences between the reasons of the CLSCs choosing the not invest strategy in the scenario of HSC and MEPPP and the scenario of HSC and LEPPP. The EPPP in this scenario is negative, but the sum of the reward and penalty of the government supervision is bigger than its absolute value, which means the CLSC choosing the invest strategy will obtain positive profit if and only if the government implement supervision. Considering that it is impossible for the government to choose the strategy of supervise, the CLSC choosing the invest strategy will not receive the reward from the government while the CLSC choosing the not invest strategy will not suffer the penalty from the government, so the CLSC must choose the not invest strategy.

$P<C_g$, $E>0$

These two expressions show the scenario of high supervision cost and high environmental protection premium profit (HSC and HEPPP) because that the government supervision cost is higher than the penalty cost imposed to the CLSC who adopt not invest strategy and the sum of the EPPP pluses the government's reward and penalty is lower than zero. HEPPP means the extra profit from the invest strategy, even which doesn't include the reward and penalty from the government, is bigger than the investment cost. In this scenario, there are four equilibrium points in the evolutionary game dynamic equations, which are $O(0,0), A(1,0), B(0,1), C(1,1)$. The stability analysis of these four equilibrium points is shown in Table 7.

From Table 7, the equilibrium stable point (ESS) is B(0,1) for the two game parties in the HSC and MEPPP scenario, the ESS represents that the government will certainly choose the not supervise strategy while the CLSC will certainly choose the invest strategy. In this scenario, because the EPPP is very high and positive, whether the government subsidies or not, the CLSCs will spontaneously choose the invest strategy to improve the effectiveness and the cleanness of its disassembly and remanufacturing processes which can increase its profit and decrease the pollution simultaneously. Based on the idea of improving the environmental recollection and green development, the

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$E(P-C_g)$	-	$P-C_g+E$	+	Saddle point
A	$(P-C_g)(-E-A-P)$	-	$A+C_g+E$	+	Saddle point
B	$E(C_g+A)$	-	$-E-C_g-A$	+	Saddle point
C	$(C_g+A)(-E-A-P)$	-	C_g-P-E	+	Saddle point
D	$\frac{E(C_g+A)(C_g-P)(A+P+E)}{(A+P)^2}$	+	0	+	Center point

Table 3: The stability analysis under the LSC and MEPPP scenario.

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$E(P-C_g)$	+	$P-C_g+E$	+	Unstable
A	$(P-C_g)(-E-A-P)$	-	$E(C_g+A)$	+	Saddle point
B	$E(C_g+A)$	+	$-E-C_g-A$	-	ESS
C	$(C_g+A)(-E-A-P)$	-	C_g-P-E	-	Saddle point

Table 4: The stability analysis under the LSC and HEPPP scenario.

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$E(P-C_g)$	+	$P-C_g+E$	-	ESS
A	$(P-C_g)(-E-A-P)$	-	$A+C_g+E$		Saddle point
B	$E(C_g+A)$	-	$-E-C_g-A$		Saddle point
C	$(C_g+A)(-E-A-P)$	+	C_g-P-E	+	Unstable

Table 5: The stability analysis under the HSC and LEPPP scenario.

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$E(P-C_g)$	+	$P-C_g+E$	-	ESS
A	$(P-C_g)(-E-A-P)$	-	$E(C_g+A)$	+	Saddle point
B	$E(C_g+A)$	+	$-E-C_g-A$	+	Unstable
C	$(C_g+A)(-E-A-P)$	-	C_g-P-E		Saddle point

Table 6: The stability analysis under the HSC and MEPPP scenario.

government may carry out the supervise strategy by a certain proportion in the beginning. As times go on, the government would find that the CLSCs must implement the invest strategy, and its supervision cost is very higher than the penalty, so the government will only take the not supervise strategy in the end.

Numeric Simulation Analysis

Some numerical simulations using Matlab2010 are made to verify the conclusions of equilibrium analysis under the above six scenarios, and reveal the evolution paths of the initial values of invest ratio and supervise ratio visually. We designs five initial value sets of α and β, which are [0.1,0.9], [0.3,0.7], [0.5,0.5], [0.7,0.3], [0.9,0.1] respectively, and the simulation experiments under these sets are labeled as Z1~Z5 correspondingly. The same parameters for the six scenarios are set as following: the simulation time is set from 0 to 100 unit time, the values of P, A, R, h, and H are set as 3, 4, 20, 5, and 8 respectively. Other simulation parameters are written under the simulation evolutionary figures. The horizontal and vertical axes in the simulation evolutionary figures represent the proportion of governments' choice of supervise strategy α and the proportion of closed-loop supply chains' choice invest strategy β respectively.

Figure 1 shows the evolutionary paths of the governments and the CSLCs' strategy in the LSC and LEPPP scenario from different initial values of [α,β] to the final ESS point A(1,0). As can be seen from Figure 1, when the initial value of β is big, likes in the sets of Z1~Z4, the evolution path is that the value of β decreases fast to 0 firstly and the value of α decreases a little at the same time, then the value of α increases fast to 1, and finally the two values reach the ESS point A(1,0); when the initial value of β is small, likes in the set of Z5, the evolution path is that the value of β decreases fast to 0 firstly and the value of α increases a little at the same time, then the value of α increases fast to 1, and finally the two values reach the ESS point A(1,0). The simulation figure shows the internal rules of the games. In the five initial sets, there are specific proportions of the CLSCs choosing invest strategy at the beginning of the experiments, but due to the EPPP is lower than the profit of taking not invest strategy, the CLSCs prefer to give up government reward and quickly choose the not invest strategy at the risk of being punished. When the proportion of the CLSC population adopting the not invest strategy is less than 10%, it will stimulate the government to intensify the supervision rapidly until full supervision.

Figure 2 shows there is no ESS for the CSLCs and the government in the LSC and MEPPP scenario. Considering the analysis in the section 2.2 and Figure 2, we can see that the game system only obtains the central point D, that is, the two groups will adopt a mixed strategy D(0.57, 0.14). This result illustrates the strategy selection behaviors of the two parties are interdependent to each other, and present as a

Equilibrium point	Determinant of J	Sign	Trace of J	Sign	Result
O	$P-C_g+E$	-	$P-C_g+E$		Saddle point
A	$(P-C_g)(-E-A-P)$	+	$A+C_g+E$	+	Unstable
B	$-E-C_g-A$	+	$-E-C_g-A$	-	ESS
C	$(C_g+A)(-E-A-P)$	-	C_g-P-E		Saddle point

Table 7: The stability analysis under the HSC and HEPPP scenario.

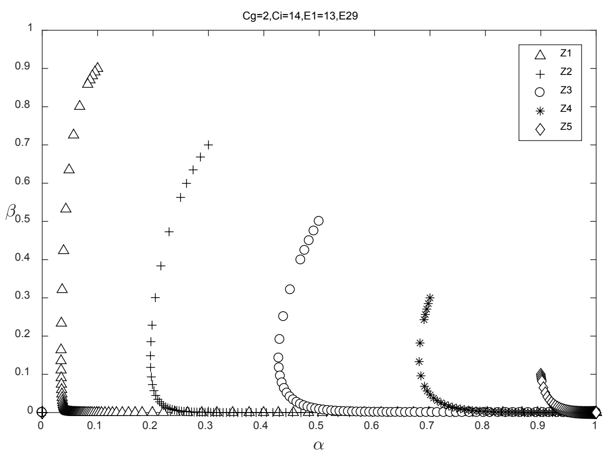

Figure 1: Evolutionary paths of governments and CSCLs' strategy in the LSC and LEPPP scenario.

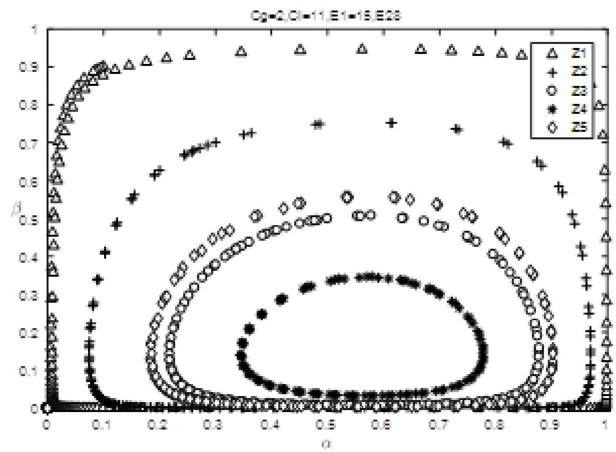

Figure 2: Evolutionary paths of governments and CSLCs' strategy in the LSC and MEPPP scenario.

periodic pattern. The evolutionary dynamic paths under the different initial values of [α,β] present the following rules: When the β value is bigger than 0.14, the α value trends to 0. When the β value is smaller than 0.14, the α value trends to 1. When theαvalue is bigger than 0.57, the β value trends to 1. When the α value is smaller than 0.57, the β value trends to 0.

The rules of the α and β values' changing implicates the rules of the two parties behaviors changing in the real world. When the proportion of the CLSCs taking the invest strategy is bigger than 0.14, the government will gradually reduce the proportion of the supervising action. When the proportion of the CLSCs taking the invest strategy is less than 0.14, the government will gradually increase the proportion of the supervising action. When the probability of the government taking the supervise strategy is bigger than 0.57, the number of the CLSCs who choose the invest strategy will gradually increase. When the probability of the government taking the supervise strategy is less than 0.57, the number of the CLSCs who choose the invest strategy will gradually decrease.

Figure 3 shows the evolutionary paths of the government and the CSLCs' strategy in the LSC and HEPPP scenario from different initial values of [α,β] to the final ESS point B(0,1). As can be seen from Figure 3, when the initial value of β is small, likes in the sets of Z4 and Z5, the evolution paths is that the value of β increases fast to near 1 firstly and the value of α decreases a little at the same time, then the value of α decreases fast to 0 while the β decreases to 1 in a slower speed, and finally the two values reach the ESS point B(0,1); when the initial value of β is big, likes in the set of Z1~Z3, the evolution paths is that the value of β increases to 1 and the α decrease to 0 simultaneously at a middle speed, and finally the two values reach the ESS point B(0,1).

In the five experiments, there are some proportion of the CLSCs who does not adopt environmental protection investment strategy at the beginning, but because the premium profit of the invest strategy is obviously higher than that of the not invest strategy, the number of the CLSCs who choose the invest strategy to take the profit will quickly increase. So this trend will promote the government to choose the not supervise strategy to save the supervision and incentive costs, and finally drive the system to the state of "governing by doing nothing".

Figure 4 shows the evolutionary paths of the government and the CSLCs' strategy in the HSC and LEPPP scenario from different initial values of [α,β] to the final ESS point O(0,0). As can be seen from Figure 4, when the initial value of β is big, likes the set Z1, the evolution paths is that the values ofα and β decreases simultaneously at the beginning, and then the value of β decreases quickly to near 0, and finally the values ofα and β reach the ESS point O(0,0); when the initial value of β is some small, likes in the set of Z2~Z5, the evolution paths is that the values ofα and β decreases simultaneously until theβ equals to 0,and then the value ofα decreases quickly to 0, the ESS point O(0,0) is reached.

In the five experiments, there are some proportion of the governments who do adopt supervise strategy at the beginning, but because the supervision cost is so high that the governments gradually choose the not supervise strategy, which means that the government

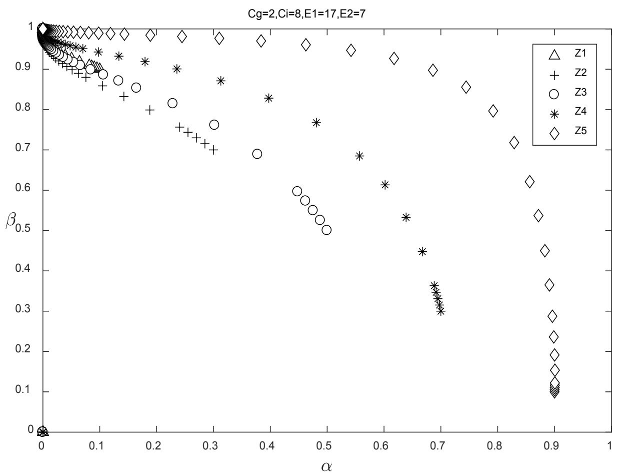

Figure 3: Evolutionary paths of governments and CSLCs' strategy in the LSC and HEPPP scenario.

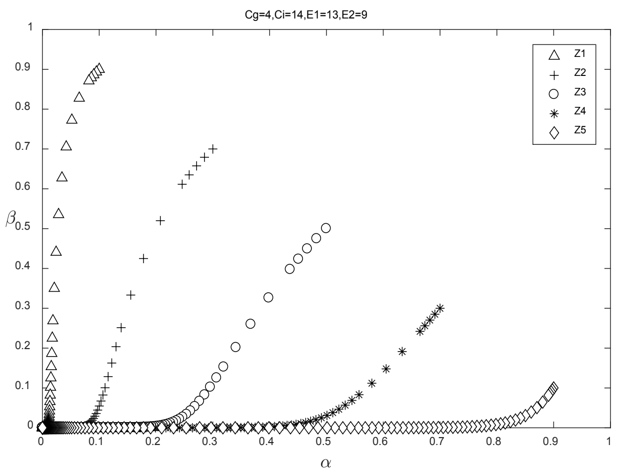

Figure 4: Evolutionary paths of governments and CSLCs' strategy in the HSC and LEPPP scenario.

would rather choose the "Let polluting, then govern it" strategy. These government behaviors guide the CLSCs to choose the not invest strategy in order to obtain higher returns.

Figure 5 shows the evolutionary paths of the government and the CSLCs' strategy in the HSC and MEPPP scenario from different initial values of [α,β] to the final ESS point O(0,0). As can be seen from Figure 5, when the initial value of α is big, likes the set Z4~Z5, the evolution paths is that the values ofα decreases rapidly while the value of β has some increase at the beginning, and then the value ofα decreases while the value of β decreases too, and finally the two values reach the ESS point O(0,0). When the initial value of α is small, likes the set Z1~Z2, the evolution paths is that the values ofα and β decreases simultaneously at the beginning, and then the decreasing speed of β is faster than that of α, and finally the two values reach the ESS point O(0,0). The main characteristics of these five evolving paths are like those of Figure 4, and there are only some differences among the processes of the two groups, so here don't present the explanations again.

Figure 6 shows the evolutionary paths of the government and the CSLCs' strategy in the HSC and LEPPP scenario from different initial values of [α,β] to the final ESS point B(0,1). As can be seen from Figure 5, when the initial value of α is big, likes the set Z5, the evolution paths is that the values of β increases rapidly while the value of α has some decrease at the beginning, and then the value of β increases slowly while the value of α decreases fast, and finally the two values reach the ESS point B(0,1). When the initial value of α is small, likes the set Z1~Z4, the evolution paths is that the values ofα and β increases simultaneously and finally reach the ESS point B(0,1). The main characteristics and the ESS points of these five evolving paths are like those of Figure 3, and there are only one important difference among the processes of the two groups, which is that the decreasing speeds of α in Figure 6 are faster than those in Figure 3 because the government supervision cost is bigger than the penalty in Figure 6 while the government supervision cost is less than the penalty in Figure 3.

Conclusions and Suggestions

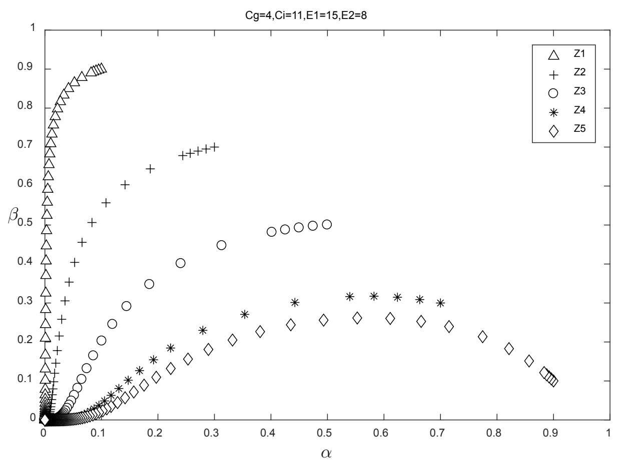

Figure 5: Evolutionary paths of governments and CSLCs' strategy in the HSC and MEPPP scenario.

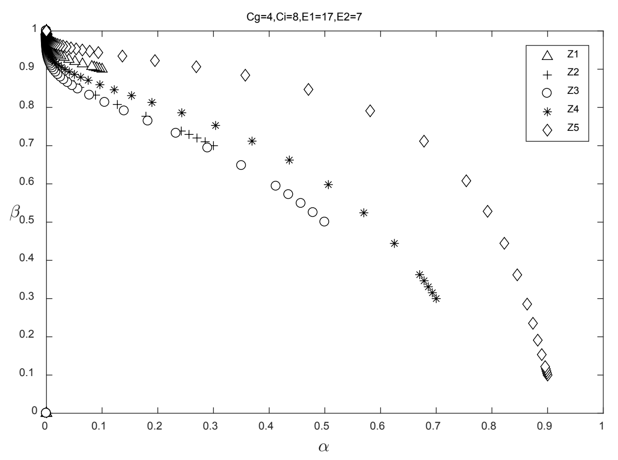

Figure 6: Evolutionary paths of governments and CSLCs' strategy in the HSC and HEPPP scenario.

This paper uses the evolutionary game theory to study the strategy selection equilibrium of the governments' supervision and the CLSCs' environmental technique and equipment's investment, and reveal the evolutionary paths in different initial status of the two groups. The results could be used as some kind of references for the government policy makers and the enterprises' managers to make proper decisions. The main conclusions and suggestions are as follows:

1. From the perspective of governments, when the supervision cost is higher than the penalty to the CLSCs who choose the not invest strategy, whether the CLSCs adopt the strategy of environmental investment or not, the government sections will eventually adopt the strategy of not supervise. Under such circumstances, if the governments want to play a supervising and guiding role in the green operation of CLSCs, its need to take measures to reduce the cost of manpower, information collecting, monitoring, detecting and testing in the process of supervision, or to increase the penalty to the CLSCs adopting not invest strategy.

2. From the perspective of CLSCs, when adopting the invest strategy can obtain higher environmental protection premium profit, whether the governments choose the supervise strategy or not, the CLSCs will eventually adopt the invest strategy to promote its ability to processing the collection goods in a more environmental way. However, due to the competitiveness among the CLSCs, the profit of choosing invest strategy is not certainly better than that of choosing not invest strategy, which will affect the internal desire of CLSCs to adopt environmental protection investment. Under such circumstances, the governments can actively investigate and publish the operation cost and profit data of different CLSCs, which will help the CLSCs to understand the benefits of invest strategy and promote them to choose the invest strategy positively, and finally the government can get free from supervising and transform the supervision role into the industry researching and guiding role.

3. When the invest strategy can not obtain high environmental protection premium profit, the CLSCs lose the enthusiasm of environmental protection investment, they do not adopt invest strategy, or dynamically adjusts their investment strategy according to the severity of government supervision. Under such circumstances, if the government want a CLSC to adopt the invest strategy actively to improve the efficiency of recycling and reuse of waste products or reduce the environmental pollution level of recycling and treatment of waste products, it should take some actions to impel relevant R&D and innovation activities which can reduce the cost by improving the technical level and the marketization level of the recycling systems. The government also can make some social guidance, such as environmental education, which can let the CLSCs' choosing invest strategy collect more discarded goods with low price than the collection quantity of the CLSCs' choosing not invest strategy, so the former may achieve high environmental premium profit and attract more CLSCs to choose the invest strategy.

4. The short-term evolution pattern of the government supervision and the closed-loop supply chain environmental investment has a strong correlation with the initial strategy proportion of the two groups, while the long-term evolution pattern has a strong correlation with the payoff parameters of the game. Therefore, in a dynamic market environment, if the governments want to achieve short-term environmental effect, they need to increase the percentage of the government sections adopting not supervise strategy to guide more members of the CLSCs to implement invest strategy. If the governments want to achieve a long-term and stable state of environmental protection, they need to take some effective measures to decrease the supervision cost and increase the environmental techniques and the income of the environmental investment.

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