The Decision of Scrap Reverse Logistics Operation Mode for Steel Enterprises Base on Evolutionary Game Theory

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Abstract

This paper discusses how steel enterprises choose the appropriate scrap reverse logistics operation mode from self-operation mode and the third party mode. To solve the problem, evolutionary game theory is used to research the game relation of cooperation between steel enterprises and the third -party enterprises. Firstly, the replication dynamic equations of both players are build based on payoff matrix .Secondly, the evolutionary stable strategies are acquired by stability analysis on evolution dynamic process of the game two players. Finally, combined with numerical simulation, some factors that impact stable strategy choice are analyzed such as initial state of system, extra income and risk cost of cooperation, invested initial cost and loss for cooperation. The conclusion provides theoretical reference for steel enterprises selecting scrap reverse logistics mode.

Keywords: scrap reverse logistics mode;evolutionary game theory;replication dynamic equation;steel enterprises

1 Introduction

During the twelfth five-year plan, China sped up the adjustment of its industrial structure and accelerated the transformation of its development mode to develop a low-carbon economy and circular economy. In this context, the steel industry, which is a great energy consumer and a serious polluter, was targeted to take a low carbon path. Therefore, many steel enterprises used a variety of strategies to actively meet the challenge of the low carbon economy. Among them, developing scrap steel industry and increasing scrap supply have a high practical value. Scrap which is different from the other wastes is the main steel-making raw material. Comprehensive energy consumption of steel production, carbon emissions and mineral resources exploittation can be reduced by using scrap in the steel production process [1]. So scrap reverse logistics is one of the effective means to implement a low carbon economy of steel industry. At present, there are self-operation mode, alliance mode and the third party logistics mode for enterprises [2]. This paper only discusses self-operation mode and the third party logistics mode. The former, is that steel enterprises themselves set up reverse logistics system and manage scrap steel reverse logistics activities of enterprise inner such as recycling, transport and reprocessing. The advantage of this mode is mainly that enterprises can control the operations of each link, efficiently recycle resources and reduce raw material cost. It also has disadvantages:transport costs are high, scrap reverse logistics may conflict with forward logistics, technical defects will hinder the development of reverse logistics, etc. The latter is that steel enterprises entrust scrap recycling work to the third party logistics in the form of an agreement and pay some service fees to them. The advantage of this mode is that the cost of building reverse logistics for steel enterprise can be reduced, more money can be saved to develop the main core business, the competitiveness of the enterprises can be improved. However, it also has certain disadvantages, such as product information are easily leaked, the number and time of recycling products are uncertain, the requirements of production cannot be met, the real power of the third party reverse logistics enterprises cannot be handled well enough that the quality of scrap steel may be poor. In a word, the two kinds of reverse logistics operational mode have both advantages and disadvantages. In practice, the decision of scrap reverse logistics operation mode is one of the key issues to consider for steel enterprises.

In recent years, many domestic and foreign scholars studied the decision-making of reverse logistics operation mode from different facets, such as, Ravi evaluated the reverse logistics operational decisions from the customer, internal business, innovation and learning, finance [3]. Ren Mingming used the fuzzy comprehensive evaluation method to establish mathematical model of operation mode selection [4], Chen Zhikui applied network analytic hierarchy process to analyze the decision of reverse logistics operation mode based on setting up evaluated index [5]. Cheng Guangping put forward an operation mode selection evaluation method aiming at the characteristics of domestic reverse logistics by using Fuzzy hierarchy analysis[6] .In the above literature, scholars largely carried out qualitative and quantitative analysis by considering the influencing

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factors of enterprise itself, few scholar considered the impact of decisions of other enterprises and the third party logistics enterprises. In fact, the problem of choosing the self-operation mode or the third party mode in scrap reverse logistics for steel enterprises can be regarded as game analysis between steel enterprises and the third-party logistics enterprises. For instance, Ceng Minggang used the "principal-agent" model to study the reverse logistics operation mode selection[7], however, he simply analyzed the game process under the assumption that two players were completely rational which did not accord with reality. Therefore, evolutionary game theory based on bounded rationality is used to study evolutionary game relation between steel enterprises and the third party logistics enterprises in the paper. The steel production enterprises choose the scrap steel reverse logistics operation mode according to the evolutionary stable strategy.

2 Evolutionary Game Model

2.1 ASSUMPTION

Evolutionary game theory originates from biological evolutionary theory. The theory based on bounded rationality hypothesis is used to analyze strategy adjustment processes, trend and local stability of limited rational players in the process of long-term repeated behavior, study subjects of the theory are groups rather than a single individual behavior[8]. In this paper, the two players are randomly assigned – one from steel enterprises group and one from the third party logistics enterprise groups respectively. The two players are random when playing the game. The game strategies of both players are cooperation and non-cooperation. The cooperation is that enterprises will contract part or all business of scrap reverse logistics out to the third party. The non-cooperation is the enterprises will not reach an agreement with the third party logistics enterprises; the enterprise itself will handle all of the scrap recycling business. Based on reference literature [9-10], one assumes that the benefits and costs of steel enterprises and third-party logistics enterprises under different strategies are as following:

D_m,D_L denote the obtained normal returns of independent operation when steel enterprises and third-party logistics enterprises choose "non-cooperation",

B_m,B_L are generated excess returns when two players cooperate,

F_m,F_L indicate risk costs of two player's cooperation,

C_m,C_L signify the initial costs which two players invest for co-operation,

V_m is the suffered loss when steel enterprises select cooperation, while the third party logistics enterprises choose non- cooperation,

V_L is the suffered loss when the third party logistics enterprises select co-operation, while steel enterprises choose non- cooperation,

Where $B_m > F_m + C_m$, $B_L > F_L + C_L$

According to the above parameters, the payoff matrix of steel enterprises and third-party logistics enterprises is shown in Table 1.

TABLE 1 Payoff matrix of steel enterprises and third-party logistics enterprises

	The third party logistics enterprises	
	Cooperation(*x*)	Non- cooperation((*1-x*)
Cooperation(y)	$D_m + B_m - C_m - F_m$, $D_L + B_L - C_L - F_L$	$D_m - C_m - V_m$, D_L
Non-cooperation(1-y)	D_m, $D_L - C_L - V_m$	D_m, D_L

2.2 THE ESTABLISHMENT OF THE REPLICATED DYNAMIC EQUATION

The expected returns of steel enterprises group selecting cooperation strategy and non-co-operation strategy are as follows:

$$u_{s1} = x(D_m + B_m - C_m - F_m) + (1-x)(D_m - C_m - V_m), \quad (1)$$

$$u_{s2} = xD_m + (1-x)D_m. \quad (2)$$

The average payoff of steel enterprises group is as follows:

$$u_{ss} = yu_{s1} + (1-y)u_{s2}. \quad (3)$$

Similarly, the expected returns of the third party logistics group selecting cooperation strategy and non-cooperation strategy are as follows:

$$u_{x1} = y(D_L + B_L - C_L - F_L) + (1-y)(D_L - C_L - V_L), \quad (4)$$

$$u_{x2} = yD_L + (1-y)D_L. \quad (5)$$

The average payoff of the third party logistics group is as follows:

$$u_x = xu_{x1} + (1-x)u_{x2}. \quad (6)$$

According to evolutionary game theory, if the fitness or payoff of one strategy is higher than the average fitness of the group, the group will trend to adopt this strategy. Namely, the growth rate of this strategy is greater than zero, which can be expressed by the following differential equation [11]:

$$\frac{dx}{dt} = [u(k,s) - u(s,s)]x_k, k = 1,2,\ldots,K \quad . \quad (7)$$

Equation (7) is replicated dynamic equation, where x_k is the proportion of using strategy k among group, $u(k,s)$ is payoff of using strategy k, $u(s,s)$ is the average payoff of the group,k denotes a different strategy, K indicates strategy number of group, s is all strategy set of group.

The replicated dynamic equation of steel enterprises selecting the "cooperation" strategy is as follows:

$$F(y)=\frac{dy}{dt}=y(u_{s1}-u_{ss})=y(1-y)(xB_m+xV_m-xF_m-C_m-V_m) \ . \tag{8}$$

Let $\frac{dy}{dt}=0$, the stabilized state points of replicated dynamic equation ,which mean the proportion y of steel enterprises selecting co-operation strategy in the dynamic process keep relatively stable equilibrium, are obtained:

$$y=0, y=1,\ \ x^*=\frac{C_m+V_m}{B_m+V_m-F_m}.$$

In the same way, the replicated dynamic equation of the third party logistics enterprises selecting the "cooperation" strategy is as follows:

$$F(x)=\frac{dx}{dt}=x(u_{x1}-u_{xx})=x(1-x)(yB_L+yV_L-yF_L-C_L-V_L). \tag{9}$$

Let $\frac{dy}{dt}=0$, the stabilized state points are obtained:

$$x=0, x=1,\ \ y^*=\frac{C_L+V_L}{B_L+V_L-F_L}$$

3 Stability Analysis Of Model

The above obtained stabilized state points are not absolute stable equilibrium. According to the stability theorem of differential equation and the nature of evolutionary stable strategy[12], the calculated state points are evolutionary stable strategy(ESS) when $\frac{dF(x)}{dx}<0$ and $\frac{dF(y)}{dy}<0$.

For the iron and steel enterprises,

$$F'(y)=(1-2y)(xB_m+xV_m-xF_m-C_m-V_m). \tag{10}$$

If $x=\frac{C_m+V_m}{B_m+V_m-F_m}$, then $F(y)\equiv 0$. This means all state points y are stable.

If $x\neq\frac{C_m+V_m}{B_m+V_m-F_m}$, $y=0$ and $y=1$ are stable state points, the two cases in this condition are as follows:

When $x>\frac{C_m+V_m}{B_m+V_m-F_m}$, $\frac{dF(y)}{dy}\Big|_{y=1}<0$, $\frac{dF(y)}{dy}\Big|_{y=0}>0$, $y=1$ is ESS;

When $x<\frac{C_m+V_m}{B_m+V_m-F_m}$, $\frac{dF(y)}{dy}\Big|_{y=0}<0$, $\frac{dF(y)}{dy}\Big|_{y=1}>0$, $y=0$ is ESS;

The conclusion can be drawn from above process analysis: when the probability of the third party logistics enterprises group choose co-operation is bigger than $\frac{C_m+V_m}{B_m+V_m-F_m}$, the final strategy of steel enterprises group is co-operation , that is to say, steel enterprises select the third party logistics mode; when the probability is smaller than $\frac{C_m+V_m}{B_m+V_m-F_m}$, the final strategy is non cooperation ,that is, steel enterprises select self-operation mode.

For the third party logistics enterprises,

$$F'(x)=(1-2x)(yB_L+yV_L-yF_L-C_L-V_L). \tag{11}$$

If $y=\frac{C_L+V_L}{B_L+V_L-F_L}$, then $F(x)\equiv 0$. This means all state points x are stable state points.

If $y\neq\frac{C_L+V_L}{B_L+V_L-F_L}$, $x=0$ and $x=1$ are stable state points, the two cases are analyzed:

when $y>\frac{C_L+V_L}{B_L+V_L-F_L}$, $\frac{dF(x)}{dx}\Big|_{x=1}<0$, $\frac{dF(x)}{dx}\Big|_{x=0}>0$ $x=1$ is ESS, that is to say, when the probability of steel enterprises groups choosing co-operation is bigger than $\frac{C_L+V_L}{B_L+V_L-F_L}$,the final strategy of the third party logistics enterprises group is co-operation;

when $y<\frac{C_L+V_L}{B_L+V_L-F_L}$, $\frac{dF(x)}{dx}\Big|_{x=1}>0$, $\frac{dF(x)}{dx}\Big|_{x=0}<0$, $x=0$ is ESS, that is, the final strategy of steel enterprises group strategy is non co-operation.

The replication dynamic equations of two players are synthetically analyzed. Their respective stable points are placed in coordinate plane $\{(x,y):0\leq x,y\leq 1\}$.There are five local equilibrium points in the plane:

$(x,y)=\{(0,0),(0,1),(1,0),(1,1),(x^*,y^*)\}$, where

$$x^*=\frac{C_m+V_m}{B_m+V_m-F_m} \qquad y^*=\frac{C_L+V_L}{B_L+V_L-F_L}$$

The stability of the equilibrium is obtained by local stability analysis on Jacobean matrix of the system [12-13]. According to method of Friedman proposed, the Jacobean matrix, the corresponding determinant and trace respectively are as follows:

$$J=\begin{bmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y}\end{bmatrix}=\begin{bmatrix}(1-2x)(yB_L+yV_L-yF_L-C_L-V_L) & x(1-x)(B_L+V_L-F_L)\\ y(1-y)(B_m+V_m-F_m) & (1-2y)(xB_m+xV_m-xF_m-C_m-V_m)\end{bmatrix}, \tag{12}$$

$$De(J)=\begin{vmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y}\end{vmatrix}, \tag{13}$$

$$Tr(J)=\frac{\partial F(x)}{\partial x}+\frac{\partial F(y)}{\partial y}. \tag{14}$$

The five local equilibrium points are analyzed by local stability analysis method. The results are shown in Table 2.

It is shown from Table 2 that there are two evolutionary stable strategies, two unstable equilibrium points and a saddle point among the five local equilibrium points. Figure 1 indicates dynamic process of evolutionary game between steel enterprises and the third party logistics enterprises. The broken line-ADB which two unstable equilibrium points A(0,1),B(1,0) and saddle point D(x^*,y^*) link is critical line of system converging to differrent states. Because o(0,0) and C(1,1) are ESS, all members either choose win-win cooperation strategy or choose independent operation(non cooperation) when the game between steel enterprises and the third party enterprises reach a stable state. Which state the game dynamic process of two players evolve to depends on the size of the divided area ADOB and ADBC by the broken line-ADB. S_{ADBC} denotes the area of zone-ADBC ,S_{ADOB} is the area of zone-ADOB.If S_{ADBC}>S_{ADOB}, the system will evolve to the direction of co-operation. If S_{ADBC}<S_{ADOB}, the system will evolve to the direction of non-cooperation. If S_{ADBC}=S_{ADOB}, the direction of system evolution is uncertain.

4 Analyses of Factors Affecting Evolutionary Stability Strategy

It is known from Figure 1. that the area of zone-ADOB is determined by coordinates of saddle point $D(x^*,y^*)$, so extra incomes B_m,B_L and risk costs F_m,$F_L$of co-operation, invested initial costs C_m,C_L and losses V_m,V_L for co-operation affect the evolution stable results between steel enterprises and the third party logistics enterprises. Besides, the initial state of system also has certain influence.

TABLE 2 The stability analysis result

Equilibrium Point	De(J)	symbol	Tr(J)	symbol	result
O(0,0)	$(C_L+V_L)(C_m+V_m)$	+	$-C_L-V_L-C_m-V_m$	-	ESS
A(0,1)	$(B_L-F_L-C_L)(C_m+V_m)$	+	$B_L-F_L-C_L+C_m+V_m$	+	instability
B(1,0)	$(B_m-F_m-C_m)(C_L+V_L)$	+	$B_m-F_m-C_m+C_L+V_L$	+	instability
C(1,1)	$(B_L-F_L-C_L)(B_m-F_m-C_m)$	+	$-B_L+F_L+C_L-B_m+F_m+C_m$	-	ESS
D(*x,*y**)**	$-\frac{(C_m+V_m)(B_m-F_m-C_m)(C_L+V_L)(B_L-F_L-C_L)}{(B_m+V_m-F_m)(B_L+V_L-F_m)}$	-	0		saddle point

4.1 INFLUENCE OF THE INITIAL STATE OF SYSTEM ON ESS

When the initial state of steel enterprises group and the third logistics enterprises group is in III-zone, that is, the probability of steel enterprises selecting cooperation is bigger than $\frac{C_L+V_L}{B_L+V_L-F_L}$ and the probability of the third logistics enterprises selecting co-operation is bigger than $\frac{C_m+V_m}{B_m+V_m-F_m}$,the game of system will finally converge to C(1,1), namely, both steel enterprises group and the third logistics enterprises group choose cooperation strategy. When the initial state is in I-zone, the system will finally converge to point o(0,0),that is, both players choose non co-operation, thus,steel enterprises only choose self-operation mode. When the initial state is in II and IV zone, the convergence of system is uncertain, it may evolve to C(1,1) or to o(0,0). If the initial state falls into II areas, the speed of steel enterprises convergence to *y=1* is greater than the speed of the third party logistics convergence to *x=0*, the final stability strategy is C(1,1).If the initial state falls into IV area, the speed of steel enterprises convergence to *y=0* is greater than the speed of the third party logistics convergence to *x=1*,the final stability strategy is o(0,0).

4.2 INFLUENCE OF EXTRA INCOMES ON ESS

It can be seen from the coordinate D(x*,y*) that values of *x** and *y** reduce respectively, the saddle point D moves to lower left direction ,the area of zone ADBC increases , on the contrary ,the area of zone ADBO reduces when extra incomes B_m,B_L of co-operation increase under the premise of other parameters constant, so system will evolve to co-operation direction along DC path. In order to intuitively display the influence of the changed parameter on the evolution strategy, numerical simulation calculation is used in the paper. Suppose that $C_m=C_L=3$, $V_m=V_L=2$,$F_m=F_L=1$ for convenience of calculation .

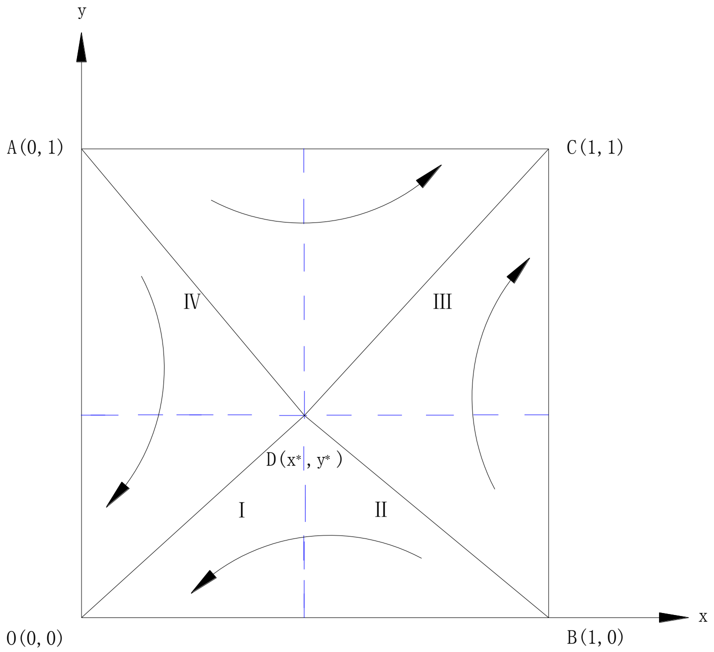

FIGURE 1 Dynamic process figure of evolutionary game between steel enterprises and the third party logistics enterprise

The calculation Process is as shown in Table 3 when the values of B_m and B_L are changed. From Figure 2, the changed path of saddle point D can be seen. The evolution path of saddle point D is from D1 to D2,D3,D4,D5, when the values of B_m and B_L are bigger and bigger.The probability of system converging to c(1,1) is larger and larger with the growing S_{ADBC} in the evolution process, so steel manufacturing enterprises and third-party logistics enterprises will be more and more inclined to choose cooperation strategy. From the above analysis , if the obtained extra incomes of the two players from cooperation become higher and higher , both sides are willing to cooperate actively.

TABLE 3 The coordinates of saddle point under different extra income

B_m=B_L	x^*	y^*
5	0.83	0.83
14	0.33	0.33
23	0.21	0.21
35	0.14	0.14
43	0.11	0.11

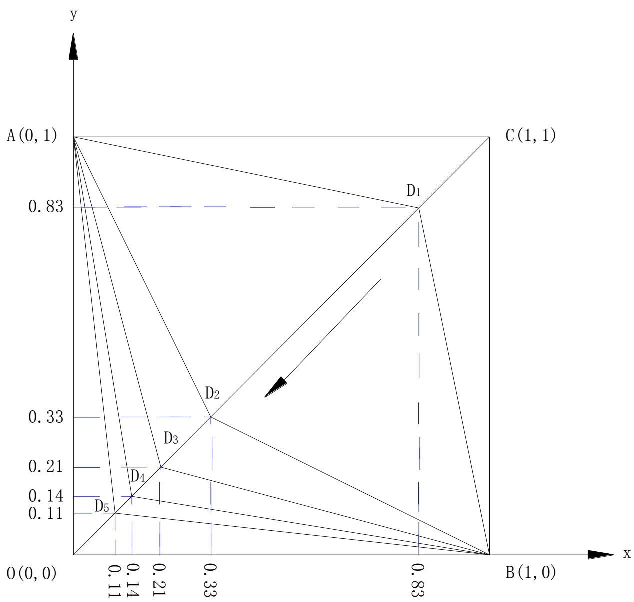

FIGURE 2 The dynamic evolution path of system in the case of extra incomes changed

4.3 INFLUENCE OF RISK COSTS ON ESS

It can be seen that values of $x^*$and y^* increase respectively, the saddle point D moves to upper right direction ,the area of zone ADBO increase , on the contrary ,the area of zone ADBC reduce when risk costs F_m,F_L of cooperation increase under the premise of other parameters constant, so system will evolve to cooperation direction along DC path. Suppose that $C_m=C_L=3$, $V_m=V_L=2$, $B_m=B_L=15$. The calculation process is as shown in Table 4 when the value of F_m and F_L is changed. From Figure.3, the changed path of saddle point D can be seen. The evolution path of saddle point D is from D1 to D2,D3,D4 when the values of F_m and F_L are bigger and bigger. The probability of system converging to o(0,0) is higher and higher with the growing S_{ADBO} in the evolution process, so steel manufacturing enterprises and third-party logistics enterprises will be more and more inclined to choose non cooperation strategy. According to the above analysis, if risk costs of the two players from co-operation are higher, both sides are not willing to co-operate.

TABLE 4 The coordinates of saddle point under different income

$F_m=F_L$	x^*	y^*
1	0.31	0.31
5	0.42	0.42
7	0.50	0.50
9	0.63	0.63

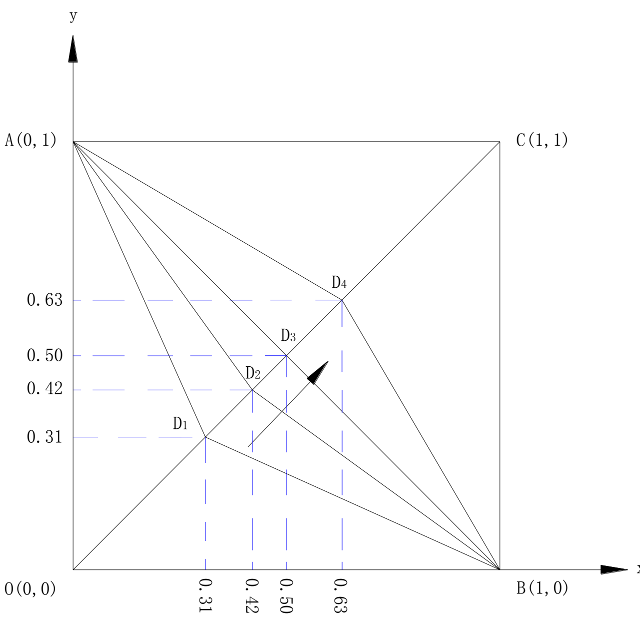

FIGURE 3 The dynamic evolution path of system in the case of risk cost changed

4.4 INFLUENCE OF THE INVESTED INITIAL COSTS ON ESS

Similarly, the values of $x^*$and y^* increase respectively, the saddle point D moves to upper right direction and approaches to C(1,1) when the risk costs C_m,C_L of co-operation increase , so the probability of system converging to o(0,0) is larger and larger, that is, the chances of steel enterprises and third-party logistics enterprises choosing non-co-operation are increasing. According to the above analysis, if the invested risk costs of the two players for cooperation are higher; both sides are not willing to co-operate.

4.5 INFLUENCE OF THE SUFFERED LOSSES ON ESS

The abscissa and ordinate of saddle point D reduce respecttively when the losses V_m,V_L of cooperation are increasing under the premise of other parameters constant. If losses V_m and V_L reduce at the same rate, the abscissa and ordinate of saddle point D keep away from c(1,1)at the same speed and approach to o(0,0) eventually. If the speeds of loss costs V_m andV_L reducing are different ,the magnitudes of saddle point D declining in horizontal and vertical direction are inequality , but it approaches to o(0,0) eventually and the region-ADBC of implement co-operation for the two players are gradually enlarged. According to the above analysis, if the suffered loss of one player choosing cooperation when the other player not cooperate is higher, they are not willing to co-operate, on the contrary, they will choose co-operation.

5 Conclusions

In the paper, the problem of steel enterprise choosing the self-operation mode or the third party mode in scrap iron reverse logistics is regarded as a game problem between steel enterprises and the third party logistics enterprise. Based on evolutionary game theory, co-operation or not between steel production enterprises and the third party logistics enterprises is analyzed. By the evolution game analysis of two players, the two evolutionary stable strategies of both co-operation and non-co-operation are obtained. Finally, the extra income and risk cost from co-operation ,invested initial cost and suffered loss for co-operation which have influence on the evolution stable result are analyzed. If the extra incomes from co-operation are higher, the risk costs from co-operation, the initial costs and losses for cooperation are lower, the two players will eventually choose co-operation development, that is, steel enterprises choose the third party reverse logistics operation mode, on the contrary, they choose the self-management mode.

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