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A Study on the Strategic Stability of Government and Steel Enterprises under Carbon Trading Mechanisms

Yanyan Li[1], Hong Liu[1,*], Yan Ji[2]

[1]*School of Business Administration, University of Science and Technology Liaoning, Anshan City, 114051, China*
[2]*University of Science and Technology Liaoning, Anshan City, 114051, China*
[*]*Corresponding author*

Abstract: *Carbon dioxide produced by human production activities has led to an increase in global temperatures, thus triggering a series of climate disasters. In order to solve the frequent environmental problems, countries around the world have taken corresponding measures. This paper takes the iron and steel industry under the carbon emission constraint and carbon trading market mechanism as the research object, and analyzes the strategic choice problems of the government, manufacturers and retailers in the process of low-carbon emission reduction under the carbon constraint. An evolutionary game model is constructed to analyze the stability of the strategic choices of the government, manufacturers and retailers. It is found that, except for the equilibrium point (0,0,0), the rest of the equilibrium points can become stable equilibrium point ESS under different conditions, and the three parties interact with each other.*

Keywords: *carbon trading mechanism, low carbon, evolutionary game, steel industry, ESS*

1. Introduction

In recent years, the contradiction between development and pollution has become more and more prominent, and climate change has become a serious challenge for all mankind. In the face of many environmental problems, the Chinese government has formulated relevant policies, put forward the ambitious goal of "striving to peak carbon dioxide emissions by 2030, and striving to achieve carbon neutrality by 2060", and launched the national carbon trading market. Under the background of carbon emission constraints, the low-carbon transformation of heavily polluting enterprises involves the interest decision-making of multiple subjects, and is a process of comprehensive game-playing by all interested subjects.

At present, domestic and foreign research on carbon trading mainly focuses on the establishment of carbon trading market mechanism and carbon trading emission reduction effect and other issues. In the establishment of carbon trading market mechanism, Liu Bo et al. established a model of short-term price dynamics of carbon quota under continuous two-way auction mechanism[1], and Alberola et al. analyzed the negotiated price structure of the European trading market and the driving factors affecting the price of carbon trading[2], and Bredin and Muckley found that changes in energy prices, climate change and economic development would affect the carbon price in the carbon trading market[3]. In addition, Zhang et al. analyzed the optimal product price and carbon emission reduction benefit distribution of enterprises covered by carbon emissions trading in cooperative supply chains under different rules[4]. Lv Jingye used the method of sensitivity analysis to prove the influence of the level of economic development and energy price on carbon trading price[5]. It can be seen that domestic and foreign scholars have achieved fruitful results in the research of this field. However, the current research is mostly in the micro-level application and the operational impact on enterprise production perspective, less research on the dynamic evolution of decision-making body strategy over time under the supply chain. Therefore, this paper conducts a dynamic study on the strategy selection problems of manufacturers and retailers in the steel supply chain under the background of carbon neutrality through evolutionary game theory, to clarify the tendency of strategy selection of supply chain subjects in the steel industry and explore the stability of different equilibrium points.

2. Modeling the evolutionary game between government and steel companies

2.1. Definition of the subject of the evolutionary game

In the context of carbon neutrality, the choice of emission reduction strategies for steel supply chain players is influenced by multiple stakeholders. This paper focuses on the strategy choices of steel manufacturers and retailers under the influence of external factors such as government policies. Therefore, the core stakeholders in the evolutionary game model are the government, manufacturers and retailers. Since the goal of "carbon neutrality" was proposed, the government has supervised and assisted the steel supply chain through laws and regulations, regulated the behavior of the main actors through the reward and punishment mechanism, and formulated a scientific supervisory mechanism to regulate the enterprises in order to guarantee the sustainable development of the environment; the manufacturers, as the upstream enterprises in the steel supply chain, are also the main players in the emission reduction and the regulation of carbon emissions. Manufacturers, as the upstream part of the steel supply chain, are also the main force in reducing carbon emissions and carbon regulation; retailers, as the downstream part of the steel supply chain, are in direct contact with consumers and can respond directly to market changes. The logical relationship between the three interests is shown in Figure 1.

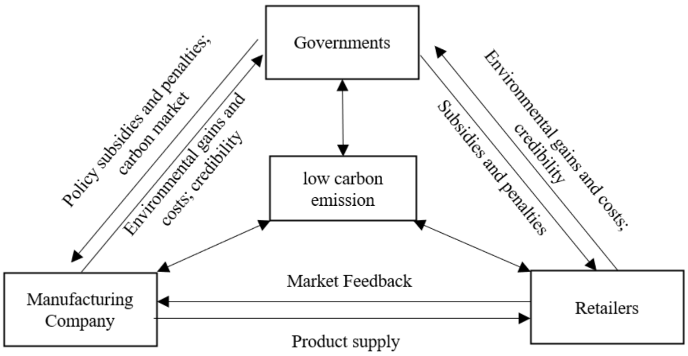

Figure 1: Logic of Interests between Government, Manufacturers

2.2. Evolutionary game modeling assumptions and payoff matrices

2.2.1. Model assumptions and parameterization

In order to construct an evolutionary game model, we analyze the strategy choices of the government, steel manufacturers and retailers, the stability analysis of equilibrium point and the influence of internal and external factors on strategy choices. This paper makes the following assumptions:

Hypothesis 1: The government, steel manufacturing industry, steel retail industry tripartite can only make limited rational decision. At the same time, the three-party game subject selection strategy is randomly paired and independent repeated game behavior.

Hypothesis 2: The government's strategic choices are "active regulation" and "passive regulation" with probabilities x and 1-x. The steel manufacturers' strategic choices are "low-carbon production" and "traditional production" with probabilities y and 1-y respectively. The strategic choices for steel manufacturers are "low carbon production" and "traditional production", with probabilities of y and 1-y. The strategic choices for steel retailers are "low carbon marketing" and "traditional marketing", with probabilities of z and 1-z, where x, y, and 1-z. z, where the values of x, y, and z are all in [0,1].

Hypothesis 3: When the steel manufacturer chooses the traditional production method, the production cost per unit of product is C_1, and the sales price per unit of product is P_1; the steel retailer wholesales the product from the manufacturer and the wholesale volume keeps the same with the sales volume as q, and the retail price is P_2, and $P_2>P_1$. When the consumers' awareness of the low carbon is sufficiently high, the price of the product will no longer be increased after the reduction of emissions, and the impact of the reduction of emissions on the demand is only taken into account. To simplify the calculation, assume that the market demand will increase by β and $\beta \in [1,2]$ when one of the manufacturer and retailer chooses the low-carbon strategy. Since the manufacturer and the retailer belong to the same supply chain, the market demand becomes βq[6][7].

Hypothesis 4: The steel manufacturer is an enterprise under the carbon emission regulation and can

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trade in the carbon trading market. When the manufacturer carries out traditional production, the carbon emission per unit of product is e_0, and when it carries out low-carbon production, the carbon emission per unit of product is e_0-e_1, and the amount of emission reduction is e_1. When the mechanism of the carbon trading market is in operation, the manufacturer's remaining carbon emission allowances due to the reduction of emissions can be sold in the carbon trading market, and it can obtain additional revenue $A=h[E-q(e_0-e_1)]$; the manufacturer does not have a low carbon and the resultant carbon emissions exceed the standard, and it needs to pay an additional expenditure $B=h(qe_0-E)$. Where E refers to the manufacturer's carbon emission limit under the carbon regulation, and h is the market trading price per unit of carbon emission in the carbon trading market. In addition, $0<q(e_0-e_1)<E<qe_0$ [8].

Hypothesis 5: The cost of abatement effort for a manufacturer choosing low-carbon production is $\frac{1}{2}k_1e_1^2$, and the cost of marketing effort for a retailer choosing low-carbon marketing is $\frac{1}{2}k_2g^2$, where g is the level of marketing effort of the retailer, and K_1, K_2 are the cost coefficients [9][10].

Hypothesis 6: When the government regulates carbon credits, the cost of regulation is C_2. When the regulation is effective, i.e., when at least one of the manufacturer and retailer chooses low carbon, the government will receive a certain policy benefit, R. When the manufacturer and retailer choose the traditional strategy the government will regulate and penalize the carbon emission behavior with M_1 and M_2, respectively. When the manufacturer and retailer choose the low carbon strategy, the government will subsidize the manufacturer and retailer with N_1 and N_2, respectively. At the same time, the government also receives an additional positive environmental benefit from the reduction of emissions by both, U. When the government does not regulate, it will have to remediate the environmental pollution caused by the manufacturer's failure to engage in low-carbon production, with a remediation cost of C_3. At the same time, the government will have to reduce its credibility due to the loss of credibility from the failure to engage in low-carbon regulation, D.

The parameter variables involved in the above assumptions are summarized in Table 1.

Table 1: Summary of game hypothesis-related parameter variables

Parameter	Description
C_1	Production costs per unit of product when steel manufacturers choose traditional production methods
C_2	Cost of government regulation
C_3	Environmental remediation costs if the government chooses not to regulate and the manufacturer chooses traditional production methods
P_1	Manufacturer's selling price per unit of product
P_2	Retailer's selling price per unit of product;$P_2>P_1>0$
q	Product sales by manufacturers and retailers
β	Consumer low carbon preference, market demand increase factor;$\beta\in(1,2]$
e_0	Manufacturer's carbon emissions per unit of product under traditional production techniques
e_1	Manufacturer's carbon emission reduction per unit of product under low carbon production technology
E	Carbon Emission Allowances for Manufacturers under Carbon Regulation; $0<q(e_0-e_1)<E<qe_0$
h	Market price per unit of carbon emissions traded in carbon markets
K_1 K_2	Manufacturer's emission reduction effort factor and retailer's marketing effort factor;K_1 $K_2\in(0,1]$
g	Level of marketing effort by retailers
A B	Extra income and extra expenses for manufacturers in the carbon trading market
M_1 M_2	Government penalties when manufacturing and retailers choose traditional strategies
N_1 N_2	Government subsidies when manufacturing and retailers choose traditional strategies
U	Positive environmental benefits to the government
D	Losses from reduced government credibility
R	Some policy gains from effective government regulation

2.2.2. Constructing the game payoff matrix

Based on the basic assumptions and the expected return analysis above, a matrix of strategic game payoffs for the government, manufacturer, and retailer can be derived, as shown in Table 2.

Table 2: The mixed strategy game matrix of government, manufacturers and retailers

Gaming Party		Retailers: Low Carbon Marketing	Retailers: Traditional Marketing
Positive Government Regulation	Manufacturers opt for low-carbon production	$-C_2+U+R$	$-C_2+R$
		$\beta q(P_1-C_1)+N_1+A-\frac{1}{2}k_1e_1^2$	$\beta q(P_1-C_1)+N_1+A-\frac{1}{2}k_1e_1^2$
		$\beta q(P_2-P_1)+N_2-\frac{1}{2}k_2g^2$	$\beta q(P_2-P_1)-M_2$
	Manufacturers choose traditional production	$-C_2-C_3+R$	$-C_2-C_3$
		$\beta q(P_1-C_1)-B-M_1$	$q(P_1-C_1)-B-M_1$
		$\beta q(P_2-P_1)+N_2-\frac{1}{2}k_2g^2$	$q(P_2-P_1)-M_2$
Negative government regulation	Manufacturers choose low carbon technologies	$U-D$	$-D$
		$\beta q(P_1-C_1)-\frac{1}{2}k_1e_1^2$	$\beta q(P_1-C_1)-\frac{1}{2}k_1e_1^2$
		$\beta q(P_2-P_1)-\frac{1}{2}k_2g^2$	$\beta q(P_2-P_1)$
	Manufacturers choose traditional technologies	$-D-C_3$	$-D-C_3$
		$\beta q(P_1-C_1)$	$q(P_1-C_1)$
		$\beta q(P_2-P_1)-\frac{1}{2}k_2g^2$	$q(P_2-P_1)$

3. Fundamental analysis and solution of game models

3.1. Analysis of the stability of the strategy of the three main parties

3.1.1. Strategic Stability Analysis of Government

Assume that the expected return to positive government regulation is V_1, the expected return to negative government regulation is V_2, and the average expected return is $\bar{V}$.

The expected return when the government chooses positive regulation is shown in equation (1). The expected return to the government when it chooses to regulate negatively is shown in equation (2). The average expected return on the government's strategy choice is shown in equation (3).

$$V_1 = yz(-C_2+U+R)+y(1-z)(R-C_2)+(1-y)z(R-C_2-C_3)+(1-y)(1-z)(-C_2-C_3)$$
$$= y(zU-C_2)-(1-y)(C_2+C_3)+(y+z-yz)R \quad (1)$$

$$V_2 = yz(U-D)+y(1-z)(-D)+(1-y)z(-D-C_3)$$
$$+(1-y)(1-z)(-D-C_3)$$
$$= y(zU-D)-(1-y)(D+C_3) \quad (2)$$

$$\bar{V} = xV_1+(1-x)V_2 = x(D-C_2)+y(zU+C_3)-(D+C_3)+x(y+z-yz)R \quad (3)$$

A replicated dynamic equation for the government's strategy choice can be derived from the government's expected returns:

$$F_1(x,y,z) = \frac{dx}{dt} = x(V_1-\bar{V}) = x(1-x)[D-C_2+(y+z-yz)R] \quad (4)$$

3.1.2. Manufacturer's Strategic Stability Analysis

$$U_1 = xz\left[\beta q(p_1-C_1)+\frac{1}{N_1}+N_1+A-\frac{1}{2}k_1e_1^2\right]$$
$$+x(1-z)\left[\beta q(p_1-C_1)+N_1+A-\frac{1}{2}k_1e_1^2\right]$$
$$+(1-x)z\left[\beta q(p_1-C_1)-\frac{1}{2}k_1e_1^2\right] \quad (5)$$
$$+(1-x)(1-z)\left[\beta q(p_1-C_1)-\frac{1}{2}k_1e_1^2\right]$$
$$= \beta q(P_1-C_1)-\frac{1}{2}k_1e_1^2+x(N_1+A)$$

The manufacturer's expected return when choosing the traditional production method is shown in equation (5)(6). The average expected return for the manufacturer's strategy choice is shown in equation

(7)(8).

$$\begin{aligned} U_2 &= xz[\beta q(p_1 - C_1) - B - M_1] + x(1-z)[q(p_1 - C_1) - B - M_1] \\ &+(1-x)z[\beta q(p_1 - C_1)] + (1-x)(1-z)q(p_1 - G_1) \\ &= z\beta q(P_1 - C_1) + (1-z)q(P_1 - C_1) - x(B + M_1) \end{aligned} \tag{6}$$

$$\begin{aligned} \overline{U} &= yu_1 + (1-y)u_2 \\ &= [z\beta + (1-z)y\beta + (1-y)(1-z)]q(P_1 - C_1) - \tfrac{1}{2}k_1e_1^2y + xy(N_1 + A) \end{aligned} \tag{7}$$

$$\begin{aligned} F_2(x,y,z) &= \tfrac{dy}{dt} = y(u_1 - \bar{u}) \\ &= y(1-y)\left[-\tfrac{1}{2}k_1e_1^2 + x(N_1 + A + B + M_1) + (1-\beta)(1-z)q(C_1 - P_1)\right] \end{aligned} \tag{8}$$

3.1.3. Strategic stability analysis of retailers

The expected benefit of the steel retailer's choice of low-carbon marketing strategy is shown in equation (9).

$$\begin{aligned} W_1 &= xy[\beta q(P_2 - P_1) + N_2 - \frac{1}{2}k_2g^2] + x(1-y)[\beta q(P_2 - P_1) + N_2 - \frac{1}{2}k_2g^2] + (1-x)y[\beta q(P_2 \\ &- P_1 - \frac{1}{2}k_2g^2] + (1-x)(1-y)[\beta q(p_2 - p_1) - \frac{1}{2}k_2g^2] \\ &= \beta q(P_2 - P_1) - \tfrac{1}{2}k_2g^2 + xN_2 \end{aligned} \tag{9}$$

The expected return for a steel retailer choosing a traditional marketing strategy is shown in equation (10). The average expected return of the steel retailer's strategy choice is shown in equation (11).

$$\begin{aligned} W_2 &= xy[\beta q(P_2 - P_1) - M_2] + x(1-y)[q(p_2 - P_1) - M_2] + (1-x)y\beta q(p_2 - P_1) \\ &+ (1-x)(1-y)q(p_2 - p_1) \\ &= y\beta q(P_2 - P_1) + (1-y)q(P_2 - P_1) - xM_2 \end{aligned} \tag{10}$$

$$\begin{aligned} \overline{W} &= zW_1 + (1-z)W_2 = [z + (1-z)y]\beta \mathrm{q}(P_2 - p_1) \\ &+(1-y)(1-z)q(P_2 - P_1) - \tfrac{1}{2}k_2g^2z + xzN_2 - x(1-z)M_2 \end{aligned} \tag{11}$$

The equation for the replication dynamics of the retailer's strategy can be derived from its expected return and average expected return:

$$\begin{aligned} F_3(x,y,z) &= \tfrac{dz}{dt} = z(W_1 - \overline{W}) \\ &= z(1-z)\left[-\tfrac{1}{2}k_2g^2 + x(N_2 + M_2) + (1-y)(\beta - 1)q(P_2 - P_1)\right] \end{aligned} \tag{12}$$

3.2. Stability analysis of equilibrium points of a three-way evolutionary game system

According to the conclusion of Reinhard's study, in asymmetric games, if the information asymmetry condition holds, the evolutionary stable strategy is a pure strategy[11]. Moreover, if the equilibrium point E is asymptotically stable, then E must be a strict Nash equilibrium i.e., a pure strategy Nash equilibrium[12]. Therefore only the asymptotic stability of the local equilibrium point needs to be discussed. According to the replicated dynamic equations of the three-way evolutionary game, i.e., F(x)=0, F(y)=0, F(z)=0 associatively can be obtained as a three-dimensional dynamical system, which has 14 equilibrium points, at this time, only the pure strategy of which is studied, i.e., $E_1(0,0,0)$,$E_2(1,0,0)$,$E_3(0,1,0)$,$E_4(0,0,1)$,$E_5(1,1,0)$,$E_6(1,0,1)$,$E_7(0,1,1)$,$E_8(1,1,1)$. In order to analyze the stability of the equilibrium point of the three-party evolutionary game system, the Jacobian matrix of the three-party evolutionary system is constructed.

$$J = \begin{bmatrix} \frac{\partial F_1}{\partial x} & \frac{\partial F_1}{\partial y} & \frac{\partial F_3}{\partial z} \\ \frac{\partial F_2}{\partial x} & \frac{\partial F_2}{\partial y} & \frac{\partial F_2}{\partial z} \\ \frac{\partial F_3}{\partial x} & \frac{\partial F_2}{\partial y} & \frac{\partial F_2}{\partial z} \end{bmatrix} = \begin{bmatrix} u_{11} & u_{12} & u_{13} \\ u_{21} & u_{22} & u_{23} \\ u_{31} & u_{32} & u_{33} \end{bmatrix} \tag{13}$$

$$\mathrm{u}_{11} = (1 - 2\mathrm{x})[\mathrm{D} - \mathrm{c}_2 + (\mathrm{y} + \mathrm{z} - \mathrm{yz})\mathrm{R}]$$

$$\mathrm{u}_{12} = \mathrm{x}(1 - \mathrm{x})(1 - \mathrm{z})\mathrm{R}$$

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$$u_{13} = x(1-x)(1-y)R$$

$$u_{21} = (N_1 + A + B + M_1)(1-y)y$$

$$u_{22} = (1-2y)[-\frac{1}{2}k_1 e_1^2 + x(N_1 + A + B + M_1) + (1-\beta)(1-z)q(C_1 - P_1)]$$

$$u_{23} = y(y-1)(1-\beta)(C_1 - P_1)q$$

$$u_{31} = z(1-z)(N_2 + M_2)$$

$$u_{32} = z(z-1)(\beta-1)(P_2 - P_1)q$$

$$u_{33} = (1-2z)[-\frac{1}{2}k_2 g^2 + x(N_2 + M_2) + (1-y)(\beta-1)q(P_2 - P_1)]$$

From Lyapunov's law, the corresponding equilibrium point is a stable equilibrium point when and only when the eigenvalues of the matrix are all less than 0. When the eigenvalues are all greater than 0, it is an unstable equilibrium point; when the eigenvalues are only individually greater than 0, it is a saddle point. Table 3 shows the eigenvalues and stability analysis of each equilibrium point

Table 3: Eigenvalues and stability of equilibrium points

Equilibrium point	Eigenvalue			Stability
	λ_1	λ_2	λ_3	
$E_1(0,0,0)$	$D-C_2$	$(1-\beta)q(C_1-P_1)-\frac{1}{2}k_1e_1^2$	$(\beta-1)q(P_2-P_1)-\frac{1}{2}k_2g^2$	Saddle point or instability
$E_2(1,0,0)$	C_2-D	$(1-\beta)q(C_1-P_1)-\frac{1}{2}k_1e_1^2+N_1+A+B+M_1$	$(\beta-1)q(P_2-P_1)-\frac{1}{2}k_2g^2+N_2+M_2$	Scenario 1
$E_3(0,1,0)$	$D-C_2+R$	$(\beta-1)q(C_1-P_1)+\frac{1}{2}k_1e_1^2$	$-\frac{1}{2}k_2g^2$	Scenario 2
$E_4(0,0,1)$	$D-C_2+R$	$-\frac{1}{2}k_1e_1^2$	$(1-\beta)q(P_2-P_1)+\frac{1}{2}k_2g^2$	Scenario 3
$E_5(1,1,0)$	C_2-D-R	$(\beta-1)q(C_1-P_1)+\frac{1}{2}k_1e_1^2-N_1-A-B-M_1$	$-\frac{1}{2}k_2g^2+N_2+M_2$	Scenario 4
$E_6(1,0,1)$	C_2-D-R	$-\frac{1}{2}k_1e_1^2+N_1+A+B+M_1$	$(1-\beta)q(P_2-P_1)+\frac{1}{2}k_2g^2-N_2-M_2$	Scenario 5
$E_7(0,1,1)$	$D-C_2+R$	$\frac{1}{2}k_1e_1^2$	$\frac{1}{2}k_2g^2$	Saddle point or instability
$E_8(1,1,1)$	C_2-D-R	λ_2	$\frac{1}{2}k_2g^2-N_2-M_2$	Scenario 6

Scenario 1: The equilibrium point $E_2(1,0,0)$ is ESS if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., $C_2-D<0,(1-\beta)q(C_1-P_1)-\frac{1}{2}k_1e_1^2+N_1+A+B+M_1<0$, $(\beta-1)q(P_2-P_1)-\frac{1}{2}k_2g^2+N_2+M_2<0$. At this point, the government will choose environmental regulation, while steel manufacturers will choose traditional production methods and retailers will choose low-carbon lifestyles. Under this strategy combination, the government enforces the environmental regulation and the environmental problems are somewhat improved. However, manufacturers and retailers continue to choose traditional methods because of the high cost of low carbon, making it difficult to further curb the carbon emission problem, and the environmental problem remains significant.

Scenario 2: The equilibrium point $E_3(0,1,0)$ is ESS if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., $D-C_2+R<0,(\beta-1)q(C_1-P_1)+\frac{1}{2}k_1e_1^2<0$. The carbon emission and environmental problems are improved with this strategy combination. However, because of the government's inaction and retailers' non-low carbon, it makes manufacturers less motivated to reduce emissions, while retailers' environmental problems are not solved.

Scenario 3: The equilibrium point $E_4(0,0,1)$ is ESS if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., $D-C_2+R<0,(1-\beta)q(P_2-P_1)+\frac{1}{2}k_2g^2<0$. In this case, the government will choose not to regulate, the manufacturer will choose the traditional production method, and the retailer will choose to carry out low-carbon marketing. Under this strategy combination, retailers take the initiative to carry out low-carbon marketing, while the government's inaction and manufacturers' polluting behaviors will still hit the retailers' low-carbon initiative, and the carbon emission and environmental pollution problems will still exist.

Scenario 4: The equilibrium point $E_5(1,1,0)$ is ESS if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., C_2-D-R <0,$(\beta-1)q(C_1-P_1)+\frac{1}{2}k_1e_1^2-N_1-A-B-M_1<0,-\frac{1}{2}k_2g^2+N_2+M_2<0$. In this scenario, the government will choose regulation, manufacturers will choose low-carbon production, and retailers will choose traditional marketing because of the high low-carbon costs. With this strategy combination, the government regulates environmentally and manufacturers choose low carbon because of profit maximization. This leads to a significant improvement in the environmental problems, the total amount of carbon emissions is controlled and the environmental problems will not deteriorate any further.

Scenario 5: The equilibrium point $E_6(1,0,1)$ is ESS if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., C_2-D-R <0,$\frac{1}{2}k_1e_1^2-N_1-A-B-M_1<0,\frac{1}{2}k_2g^2-N_2-M_2<0$. At this point, the government will choose regulation, retailers will choose low-carbon marketing, and manufacturers will choose traditional production methods. The government and retailers in this combination strategy have made efforts for low carbon emission reduction, while the manufacturer, as a major carbon emission enterprise, still chooses the traditional production method. This makes it difficult to improve the problems of environmental pollution and carbon emissions.

Scenario 6: The equilibrium point $E_8(1,1,1)$, is ES if $\lambda_1<0,\lambda_2<0,\lambda_3<0$, i.e., C_2-D-R <0,$\frac{1}{2}k_1e_1^2-N_1-A-B-M_1<0,\frac{1}{2}k_2g^2-N_2-M_2<0$. In this scenario, the government will choose to regulate, the manufacturer will choose low-carbon production, and the retailer will choose low-carbon marketing. Each game subject in this combination strategy has made actions for low carbon, which fundamentally solves the carbon emission problem and is the optimal decision.

4. Conclusions and perspectives of the study

This paper evolves the game method to analyze the influence of internal and external influences on the behavioral choices of the game subject, and through the analysis of the stability of the three-party game subject in different strategy choices. Based on the above research, the following conclusion is drawn: the strategy choice of each game subject is influenced by multiple factors. At the same time, the three interact with each other. The change of strategy of any one game subject will cause the change of strategy of other subjects. According to the analysis of the stability conditions of the six equilibrium points, it is found that the most important factor affecting the government, manufacturers and retailers is still the relationship between costs and benefits. In order to maximize the benefits, all three subjects are constantly adjusting their stability strategies.

The study of low-carbon emission reduction strategies in the steel supply chain involves a wide range of interests and game relationships between the government, enterprises and consumers, which is a complex and profound systematic problem. In this paper, the linear relationship of carbon trading mechanism is set in the process of setting the parameters of the game body, and it is not considered from the perspective of non-linear relationship, which can be studied in depth in the future research.

References

[1] Liu Bo, Zeng Yong, Li Ping. Analysis of short-term price behavior under continuous two-way auction mechanism[J]. Journal of Systems Engineering, 2007, 22(1): 20-26.
[2] Alberola E, Chevallier J, Chèze B. Price drivers and structural breaks in European carbon prices 2005–2007[J]. Energy policy, Elsevier, 2008, 36(2): 787–797.
[3] Bredin D, Muckley C. An emerging equilibrium in the EU emissions trading scheme[J]. Energy Economics, Elsevier, 2011, 33(2): 353–362.
[4] Yuejun Zhang, Yafang Sun, Baofeng Huo. The optimal product pricing and carbon emissions reduction profit allocation of CET-covered enterprises in the cooperative supply chain[J]. Annals of Operations Research, 2021.
[5] Lv Jingye, Fan Xinya, Wu Haonan. Parameter sensitivity analysis of factors affecting carbon emission right price in China[J]. Soft Science, 2021, 35(05):123-130.
[6] Xia L J. Low carbon supply chain operation coordination and optimization [M]. Beijing: people's post and telecommunications press, 2016:16-17.
[7] WANG Yiting, LI Fang. Research on green innovation game of upstream and downstream enterprises

ISSN 2616-5902 Vol. 5, Issue 23: 167-174, DOI: 10.25236/AJBM.2023.052324

in supply chain under carbon trading regulation[J]. Journal of Chongqing University of Technology (Natural Science), 2022, 36(07):238-244.

[8] WANG Wenli, CHENG Tianyu. Evolutionary game analysis of supply chain operation decision-making in the context of carbon trading[J]. Systems Engineering Theory and Practice, 2021, 41(05): 1272-1281.

[9] Chen K, Xiao T. Demand disruption and coordination of the supply chain with a dominant retailer [J]. European Journal of Operational Research, 2009, 197(1): 225-234.

[10] Xiao Chengyong, Wang Qian. A wholesale price coordination strategy for suppliers in a two-level advertising game [J]. System Science and Mathematics, 2011, 31(11): 1504-1510.

[11] Bao Chunbing, Jin Zongkai, Rong Xiaoxia, Meng Qingchun, Yu Yu. Game analysis of the evolution of pollution co-management strategies of small and medium-sized enterprises under environmental protection rigid constraints[J/OL]. China Management Science:1-12[2023-06-08]. DOI:10. 16381/j. cnki. issn1003-207x. 2021. 1236.

[12] Zeng, D. H. Asymptotic stability analysis of multi-group evolutionary game equilibrium and its application [D]. Jinan University, 2012.