The Three-Party Evolutionary Game of Cooperation Between Upstream and Downstream Enterprises Under Government Subsidies

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Abstract. The successful development of upstream and downstream enterprises cooperation need to solve the game problem among the actors. To this end, based on government subsidies, and then a tripartite game system for upstream and downstream enterprises cooperation can be constructed. The purpose of this paper is to construct a revenue matrix with different strategy combinations and to determine the expected revenue of each participant by analyzing the interrelationship between this matrix and the probability of strategy selection. In addition, based on the Malthusian principle, we propose a new replication dynamic equation for the cooperation of upstream and downstream enterprises under government subsidies, and further investigate the game evolution law of strategic behavior. Numerical analysis and system simulation results show that:(1) after a long-term evolution process, the system eventually has three stable strategies. The first one is that the government actively subsidizes, upstream and downstream enterprises actively cooperate, and consumers choose to consume; the second one is that the government does not subsidize, upstream and downstream enterprises actively cooperate, and consumers choose to consume; the third one is that the government actively subsidizes, upstream and downstream enterprises do not cooperate, and consumers choose to consume. (2) Subsidies are effective for both upstream and downstream enterprises and consumers. However, excessive subsidies will weaken the financial expenditure and hinder the government's enthusiasm of regulation. (3) Increasing the basic incentives for cooperative enterprises helps upstream and downstream enterprises to cooperate actively, thus improving the market environment. (4) The cooperative activities of upstream and downstream enterprises not only rely on the government and enterprises, but also require extensive participation of consumers. The results of this study will help inform the decision making of upstream and downstream enterprises as well as consumers, which in turn will provide strong support for promoting the quality development of the economy.

Keywords: Government; upstream and downstream enterprises; consumers; evolutionary game

1 Introduction

With the booming development of enterprises, most of the enterprises in China have also entered the acceleration path. China's "14th Five-Year Plan" for the development of small and medium-sized enterprises in 2021 proposes to enhance the ability of large and medium-sized enterprises to cooperate in their development, and for upstream and downstream enterprises, whether to

MSEA 2023, May 26-28, Nanjing, People's Republic of China

DOI 10.4108/eai.26-5-2023.2334388

cooperate is a question to be considered. On the one hand, enterprises can change their development mode and respond to the government's call for better economic development; on the other hand, given the limitations of most enterprises' internal technology research and development capabilities, it is difficult to achieve high quality production, so they need to seek technical or financial support from enterprises in the supply chain with leading capabilities covering supply chain management. Led by the leading force, upstream and downstream enterprises join together to achieve synergistic development and establish a high-quality cooperation mode[1]. However, in the process of cooperation between upstream and downstream enterprises, cost increase is an unavoidable problem. However, if the cost paid by the enterprises is much greater than the benefit it can obtain in the future, its enthusiasm and initiative in the cooperation will be weakened, and it may even appear to become negative in the cooperation[2]. Therefore, in order to solve the above problems, the article studies upstream and downstream about the propensity to cooperate, explores its evolutionary mechanism and its influencing factors, and then puts forward corresponding suggestions.

In the process of practice, enterprises cooperation is usually promoted and influenced by multiple interest subjects. Stimulated by government subsidies, multiple interest subjects check and balance each other and play each other, which will have different degrees of influence on the implementation effect of enterprises cooperation[3]. The relevant research is reflected in two aspects, one is the relationship between the enterprises interest structure of the game subjects[4] and the management system hierarchy characteristics[5]. Based on the cooperative enterprises and its management hierarchy, a three-party game situation is common in the game process. The government is an important manager in the game system and is regarded as the first subject. At the same time, there are differences between the two subsequent subjects. In terms of structural relations, the relationship between the government and enterprises is very clear and therefore can be used as the first and second game subjects. As for the third-party subjects, they vary depending on the object of study, such as consumers[6, 7] and third-party institutions[8, 9]. Overall, the three parties of the game are basically not internally related but independent of each other. On the other hand, the game is played by the relevant enterprises as the second and third parties with the support of the government side, such as the stable game of standard-essential patent licensing enterprises to standard-essential patent implementation enterprises [10], and the synergistic game between business employees and traditional enterprises[11]. Secondly, the influencing factors of enterprises cooperation, whose influencing factors include internal factors of enterprises themselves and external factors such as the existence of third parties like the government. Specific internal factors are mainly the degree of knowledge complementarity[12], transaction costs[13], the distribution ratio of benefits[14], etc. Internal factors are the essence of enterprises cooperation and are not easily influenced by the external environment. The external factors are mainly government policies, in which the government's punishment and subsidy mechanisms can also influence upstream and downstream enterprises to implement cooperation strategies[15,16,17], while the external factors are easily affected by the external environment.

In summary, the existing studies mainly focus on the construction of upstream and downstream enterprises cooperation models and the influencing factors. However, most of the research studies on the cooperation of upstream and downstream enterprises are too simplified, and few scholars have studied the problems related to the cooperation of upstream and downstream enterprises in the case of government incentives and penalties. Therefore, this paper uses evolutionary game theory, takes whether upstream and downstream enterprises cooperate and

whether consumers consume behavior as the research object, considers the influence of government rewards and punishments, constructs the evolutionary game model of enterprises cooperation and consumer consumption behavior, analyzes the evolutionary path of cooperation and consumption behavior of both sides of the game and the influencing factors, and finally, conducts numerical simulation of the model built in this paper to verify the accuracy of the research conclusions .

2 Model Construction

2.1 Problem Description

In the new development pattern, for the high-quality development of enterprises, enterprises cooperation is the basic guide, and government subsidy strategy is an effective measure. Under the role of government subsidies, the game guiding the cooperative development of the three parties of interest are: government, upstream and downstream enterprises, and consumers. The government is not only the designer and collector of subsidies, but also the promoter and guide of upstream and downstream enterprises' cooperation, and its main responsibility is to transform the traditional enterprises operation mode by means of financial subsidies, tax revenues and other means. Upstream and downstream enterprises are the leaders of promoting cooperation, and their responsibility is to invest capital, technology and guarantee under the situation of government-guided cooperation subsidies and changes in market demand of enterprises, so as to facilitate product adjustment and upgrading through multi-party cooperation to achieve 1+1>2 production efficiency and adapt to the new business environment. Consumers are the important consumer group for the stable development of enterprises cooperation, and they are the main force of market demand, and their consumption behavior gradually forms new needs, which plays a guiding role for the producers to adjust and upgrade products. The structure of the three-party game relationship is shown in Figure 1.

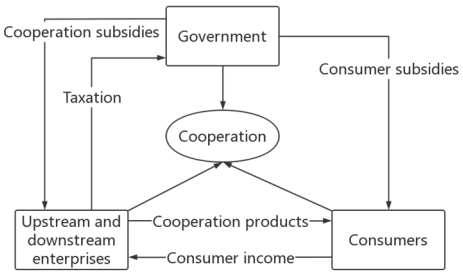

Fig 1. Three-party game relationship diagram

2.2 Basic assumptions

The government, upstream and downstream enterprises and consumers are all limited rational groups. The strategy set of the government is (active subsidy, no subsidy), the strategy set of upstream and downstream enterprises is (active cooperation, no cooperation), and the strategy set of consumers is (willing to consume, unwilling to consume).

Hypothesis 1: Each game subject corresponds to two choice strategies. The specific situation is shown in Table 1.

Table 1. Game subject strategy selection settings

participant	Probability
Government	Active Subsidy①.Probability:x
	No subsidy②.Probability:1-x
Upstream and downstream enterprises	Active Cooperation③.Probability:y
	Non-cooperation④.Probability:1-y
Consumers	Willingness to consume⑤.Probability:z
	Unwillingness to consume⑥.Probability:1-z

Hypothesis 2: Government, upstream and downstream enterprises, consumer decisions are not influenced by other game subjects.

Hypothesis 3: The government actively subsidizes will get the reward S from the higher level, and the subsidy given to the enterprises is S1, and S>S1.

Hypothesis 4: The inventory of upstream and downstream enterprises is gradually depreciated by time, assuming that the value of the inventory of cooperative enterprises is 1/2 of the market price and the value of the inventory of cooperative enterprises is 1/3 of the market price. If enterprises actively cooperate they will also receive additional subsidies E, which will be borne by the government's superior when the government actively subsidizes them and by the government when it does not.

Hypothesis 5: Consumers will use the product while consuming, and their consumption amount and product utilization are highest when the government actively subsidizes and the upstream and downstream enterprises actively cooperate; and lowest when the government does not subsidize and the upstream and downstream enterprises do not cooperate, and the consumption amount is greater than the part of the government subsidy to consumers, and the product Use efficiency decreases with the amount of consumption, that is $U1 > D1 > U2 > D2 > U3 > D3 > D4 > U4 > M$.

2.3 Variable Descriptions

The parameters and variables of the tripartite game of upstream and downstream enterprises development under government subsidies are set as shown in Table 2.

Table 2. Basic parameters and variables of the three-party game

Variables	Expression of meaning
S1	Initial amount of subsidies
ρ	Tax rates
M	Government subsidies for consumption
S	Basic rewards for active subsidies distribution
E	Basic rewards for active cooperation
C3	Non-cooperative costs for upstream and downstream enterprises
C4	cooperative costs for upstream and downstream enterprises

Di(i=1,2,3,4)	The amount of money consumers spend under different strategies
Ui(i=1,2,3,4)	The degree of utilization of products purchased by consumers

2.4 Game Gain Matrix

The three-party game is a strategy combination and selection process, and the game payoffs under different strategy combinations have variability, as shown in Table 3, which represents the payoff matrix under eight strategy combinations.

Table 3. Benefit matrix of green logistics tripartite game under strategy combination

Strategy combinations	Government	Upstream and downstream enterprises	Consumers
①+③+⑤	S+ρD1-M-S1	E+(1-ρ)D1+S1-C4	U1+M-D1
①+③+⑥	S-S1	E+1/2D1+S1-C4	0
①+④+⑤	S+ρD3-M-S1	1/3(D1-D3)+(1-ρ)D3+S1-C3	U3+M-D3
①+④+⑥	S-S1	1/3D1+S1-C3	0
②+③+⑤	ρD2-E	E+1/2(D1-D2)+(1-ρ)D2-C4	U2-D2
②+③+⑥	-E	E+1/2D1-C4	0
②+④+⑤	ρD4	1/3(D1-D4)+(1-ρ)D4-C3	U4-D4
②+④+⑥	0	1/3D1-C3	0

3 Three-party evolutionary game model

3.1 Expected returns from the three parties

In an evolutionary game, the choice of strategies is a dynamic adjustment process, with the average expected return seeking equilibrium in the limited rationality of the parties to the game. The average expected returns of the three parties in the game of upstream and downstream enterprises development under government subsidies can be obtained through the probability of strategy choice and the corresponding expected returns.

Let $\mathrm{Eg(X)}$ be the expected return from active government subsidies, and from the interaction of the variables of interest, it follows that：

$$\mathrm{Eg(X)} = \mathrm{yz(S+\rho D1-M-S1)+y(1-z)(S-S1)+(1-y)z(S+\rho D3-M-S1)+(1-y)(1-z)(S-S1)} \quad (1)$$

$$\mathrm{Eg(1-X)} = \mathrm{yz(\rho D2-E)-y(1-z)E+(1-y)z\rho D4} \quad (2)$$

The average expected return to government is：

$$\overline{\mathrm{Eg}} = \mathrm{xEg(X)+(1-x)Eg(1-X)} \quad (3)$$

Let $\mathrm{El(Y)}$ be the expected return from active government subsidies, it follows that：

$$\mathrm{El(Y)} = \mathrm{xz(E+(1-\rho)D1+S1-C4)+x(1-z)(E+\frac{1}{2}D1+S1-C4)+(1-x)z[E+\frac{1}{2}(D1-D2)+(1-\rho)D2-C4]+(1-x)(1-z)[E+\frac{1}{2}D1-C4]} \quad (4)$$

$$\mathrm{El(1-Y)} = \mathrm{xz(\frac{1}{3}(D1-D3)+(1-\rho)D3+S1-C3)+x(1-z)(\frac{1}{3}D1+S1-C3)+(1-x)z[\frac{1}{3}(D1-D4)+(1-\rho)D4-C3]+(1-x)(1-z)[\frac{1}{3}D1-C3]} \quad (5)$$

The average expected return to government is：

$$\overline{\mathrm{El}} = \mathrm{yEl(Y)} + (1-\mathrm{y})\mathrm{El}(1-\mathrm{Y}) \quad (6)$$

Let $\mathrm{Ec(Z)}$ be the expected return from active government subsidies, it follows that:

$$\mathrm{Ec(Z)} = \mathrm{xy(U1+M-D1)} + (1-\mathrm{x})\mathrm{y(U2-D2)} + \mathrm{x}(1-\mathrm{y})(\mathrm{U3+M-D3}) + (1-\mathrm{x})(1-\mathrm{y})(\mathrm{U4-D4}) \quad (7)$$

$$\mathrm{Ec}(1-\mathrm{Z}) = 0 \quad (8)$$

The average expected return to government is:

$$\overline{\mathrm{Ec}} = \mathrm{zEc(Z)} + (1-\mathrm{z})\mathrm{Ec}(1-\mathrm{Z}) \quad (9)$$

3.2 Evolutionary game replication dynamic equations and strategies

Let $\mathrm{F(X)}$, $\mathrm{F(Y)}$ and $\mathrm{F(Z)}$ be the rates of change of the probabilities of the government-led side, the enterprises implementation side and the third-party monitoring side choosing to strengthen regulation, strict emission reduction and active inspection respectively, corresponding to the replication dynamic equation of each party.

3.2.1 Government evolutionary game

For the government-led side, by the Malthusian dynamic evolution rule, there is:

$$\mathrm{F(X)} = \mathrm{x(Eg(X)} - \overline{\mathrm{Eg}}) = \mathrm{x}(1-\mathrm{x})(\mathrm{Eg(X)} - \mathrm{Eg}(1-\mathrm{X})) = \mathrm{x}(1-\mathrm{x})\{\mathrm{yz\rho(D1-D2-D3+D4)+yE+z(\rho D3-\rho D4-M)+S-S1}\} \quad (10)$$

Let F(x) = 0, at this time all x are in a stable state of evolution, that is, no matter how the government chooses to "subsidize" and "not subsidize" the initial proportion, the proportion will not change with the change of time, the equilibrium point of the possible evolutionary process is obtained as follows.

When $y = y0 = \frac{\mathrm{S1-S-z(\rho D3-\rho D4-M)}}{\mathrm{z\rho(D1-D2-D3+D4)+E}}$, F(X)=0, which means that all the points on the x-axis are in a stable state, i.e. the government strategy choice does not change with time.

When $y \neq \frac{\mathrm{S1-S-z(\rho D3-\rho D4-M)}}{\mathrm{z\rho(D1-D2-D3+D4)}}$, x=0 and x=1 are the 2 possible equilibrium points of F(X), which is the stable equilibrium point of the evolutionary game (ESS) according to the stability theorem of the replication dynamic equation.

Taking the partial derivative of F(X) yields:

$$\frac{\partial F(x)}{\partial x} = (1-2\mathrm{x})\{\mathrm{yz\rho(D1-D2-D3+D4)+yE+z(\rho D3-\rho D4-M)+S-S1}\} \quad (11)$$

When $\mathrm{D1-D2+E} > \mathrm{D3-D4}$ and $\mathrm{y} < \mathrm{y0}$, $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=0}} < 0$ and $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=1}} > 0$, at this point x=0 is the equilibrium point in the evolution of government subsidies, i.e. the government tends to choose not to subsidize; when $\mathrm{D1-D2+E} > \mathrm{D3-D4}$ and $\mathrm{y} > \mathrm{y0}$, $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=0}} > 0$ and $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=1}} < 0$, at this point x=1 is the equilibrium point in the evolution of government subsidies, i.e. the government tends to choose to actively subsidize. Conversely, when $\mathrm{D1-D2+E} < \mathrm{D3-D4}$ and $\mathrm{y} < \mathrm{y0}$, $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=0}} > 0$ and $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=1}} < 0$, at this point x=1 is the equilibrium point in the evolution of government subsidies, i.e. the government tends to choose active subsidies; when $\mathrm{D1-D2+E} < \mathrm{D3-D4}$ and $\mathrm{y} > \mathrm{y0}$, $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=0}} < 0$ and $\frac{\partial \mathrm{F(x)}}{\partial \mathrm{x}}|_{\mathrm{x=1}} > 0$, at this point x=0 is the equilibrium point in the evolution of government subsidies, i.e. the

government tends to choose no subsidies.

3.2.2 Upstream and downstream enterprises evolutionary game

Similarly, the replication dynamics equation for upstream and downstream enterprises is as follows:

$$F(Y) = y(El(Y) - \overline{El}) = y(1-y)(Eg(Y) - Eg(1-Y)) = y(1-y)\{xz[(\tfrac{1}{2} - \rho)D1 - (\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D3 + (\tfrac{2}{3} - \rho)D4] + z[(\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D4] + [E + \tfrac{1}{6}D1 - C4 + C3]\} \quad (12)$$

Let F(y)=0, at this time all y are in a stable state of evolution, that is, no matter how the initial proportion of enterprises choose "cooperation" and "non-cooperation", the proportion will not change with the change of time, the equilibrium point of the evolutionary process may be obtained as follows.

When $x = x0 = \frac{-[E+\frac{1}{6}D1-C4+C3]-z[(\frac{1}{2}-\rho)D2-(\frac{2}{3}-\rho)D4]}{z[(\frac{1}{2}-\rho)D1-(\frac{1}{2}-\rho)D2-(\frac{2}{3}-\rho)D3+(\frac{2}{3}-\rho)D4]}$, F(Y)=0, which means that all the points on the y-axis are in a stable state, i.e. the upstream and downstream enterprises strategy choice does not change with time.

When $x \neq \frac{-[E+\frac{1}{6}D1-C4+C3]-z[(\frac{1}{2}-\rho)D2-(\frac{2}{3}-\rho)D4]}{z[(\frac{1}{2}-\rho)D1-(\frac{1}{2}-\rho)D2-(\frac{2}{3}-\rho)D3+(\frac{2}{3}-\rho)D4]}$, y=0 and y=1 are the 2 possible equilibrium points of F(Y), which is the stable equilibrium point of the evolutionary game (ESS) according to the stability theorem of the replication dynamic equation.

Taking the partial derivative of F(Y) yields:

$$\frac{\partial F(y)}{\partial y} = (1-2y)\{xz[(\tfrac{1}{2} - \rho)D1 - (\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D3 + (\tfrac{2}{3} - \rho)D4] + z[(\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D4] + [E + \tfrac{1}{6}D1 - C4 + C3]\} \quad (13)$$

When $(\frac{1}{2} - \rho)(D1 - D2) > (\frac{2}{3} - \rho)(D3 - D4)$ and $x < x0$, $\frac{\partial F(y)}{\partial y}|_{y=0} < 0$ and $\frac{\partial F(y)}{\partial y}|_{y=1} > 0$, at this point y=0 is the equilibrium point in the evolution of upstream and downstream enterprises, i.e. the upstream and downstream enterprises tend to choose not to cooperate; when $(\frac{1}{2} - \rho)(D1 - D2) > (\frac{2}{3} - \rho)(D3 - D4)$ and $x > x0$, $\frac{\partial F(y)}{\partial y}|_{y=0} > 0$ and $\frac{\partial F(y)}{\partial y}|_{y=1} < 0$, at this point y=1 is the equilibrium point in the evolution of upstream and downstream enterprises, i.e. the upstream and downstream enterprises tend to choose to actively cooperate. Conversely, when $(\frac{1}{2} - \rho)(D1 - D2) < (\frac{2}{3} - \rho)(D3 - D4)$ and $x < x0$, $\frac{\partial F(y)}{\partial y}|_{y=0} > 0$ and $\frac{\partial F(y)}{\partial y}|_{y=1} < 0$, at this point y=1 is the equilibrium point in the evolution of upstream and downstream enterprises, i.e. the upstream and downstream enterprises tend to choose actively cooperate; when $(\frac{1}{2} - \rho)(D1 - D2) < (\frac{2}{3} - \rho)(D3 - D4)$ and $x > x0$, $\frac{\partial F(y)}{\partial y}|_{y=0} < 0$ and $\frac{\partial F(y)}{\partial y}|_{y=1} > 0$, at this point y=0 is the equilibrium point in the evolution of upstream and downstream enterprises, i.e. the upstream and downstream enterprises tend to choose not to cooperate.

3.2.3 Consumers evolutionary game

Similarly, the replication dynamics equation for consumers is as follows:

$$F(Z) = z(Ec(Z) - \overline{Ec}) = z(1-z)(Eg(Z) - Eg(1-Z)) = z(1-z)\{xy(U1 - U2 - U3 +$$

$$U4 - D1 + D2 + D3 - D4) + x(U3 - U4 + M - D3 + D4) + y(U2 - U4 - D2 + D4) + U4 - D4\} \quad (14)$$

Let F(z)=0,At this time all z are in a stable state of evolution, that is, no matter how the initial proportion of consumers choose to "consume" and "not consume", the proportion will not change with the change of time, the equilibrium point of the possible evolutionary process is obtained as follows.

When $y = y0 = \frac{D4-U4-x(U3-U4+M-D3+D4)}{x(U1-U2-U3+U4-D1+D2+D3-D4)+(U2-U4-D2+D4)}$, F(Z)=0, which means that all the points on the z-axis are in a stable state, i.e. the consumers strategy choice does not change with time.

When $y \neq \frac{D4-U4-x(U3-U4+M-D3+D4)}{x(U1-U2-U3+U4-D1+D2+D3-D4)+(U2-U4-D2+D4)}$, z=0 and z=1 are the 2 possible equilibrium points of F(Z), which is the stable equilibrium point of the evolutionary game (ESS) according to the stability theorem of the replication dynamic equation.

Taking the partial derivative of F(Z) yields:

$$\frac{\partial F(z)}{\partial z} = (1 - 2z)\{xy(U1 - U2 - U3 + U4 - D1 + D2 + D3 - D4) + x(U3 - U4 + M - D3 + D4) + y(U2 - U4 - D2 + D4) + U4 - D4\} \quad (15)$$

When $y < y0$, $\frac{\partial F(z)}{\partial z}|_{z=0} < 0$ and $\frac{\partial F(z)}{\partial z}|_{z=1} > 0$, at this point z=0 is the equilibrium point in the evolution of consumers, i.e. the consumers tend to choose not to consume; when $y > y0$, $\frac{\partial F(z)}{\partial z}|_{z=0} > 0$ and $\frac{\partial F(z)}{\partial z}|_{z=1} < 0$, at this point z=1 is the equilibrium point in the evolution of consumers, i.e. the consumers tend to choose to consume.

3.2.4 Integrated stability of the three-party evolutionary game

Based on the analysis of the equilibrium strategies of individual subjects, the three-party evolutionary game system is further analyzed as a whole. The following eight possible game equilibrium points are obtained from F(x) = 0, F(y) = 0 and F(z) = 0: E1(0,0,0), E2(1,0,0), E3(0,1,0), E4(0,0,1), E5(0,1,1), E6(1,0,1), E7(1,1,0) and E8(1,1,1).

At this point, the Jacobian matrix of the three-way evolutionary game is:

$$\begin{bmatrix} F11 & F12 & F13 \\ F21 & F22 & F23 \\ F31 & F32 & F33 \end{bmatrix}$$

$$F11 = (1 - 2x)\{yz\rho(D1 - D2 - D3 + D4) + yE + z(\rho D3 - \rho D4 - M) + S - S1\} \quad (16)$$

$$F22 = (1 - 2y)\{xz[(\tfrac{1}{2} - \rho)D1 - (\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D3 + (\tfrac{2}{3} - \rho)D4] + z[(\tfrac{1}{2} - \rho)D2 - (\tfrac{2}{3} - \rho)D4] + [E + \tfrac{1}{6}D1 - C4 + C3]\} \quad (17)$$

$$F33 = (1 - 2z)\{xy(U1 - U2 - U3 + U4 - D1 + D2 + D3 - D4) + x(U3 - U4 + M - D3 + D4) + y(U2 - U4 - D2 + D4) + U4 - D4\} \quad (18)$$

According to evolutionary game theory, the game equilibrium point is the evolutionary stability point (ESS) of the system when all eigenvalues of the Jacobian matrix are negative. At this point, the stability analysis of the equilibrium points E1-E8 is shown in Table 4.

Since E1(0,0,0), E2(1,0,0), E3(0,1,0), E4(0,0,1), and E7(1,1,0) have eigenvalues greater than 0 and do not satisfy the condition of stability. Therefore, only the stability of three game

equilibrium points, E5(0,1,1), E6(1,0,1), and E8(1,1,1), is analyzed, and the following three conditions exist.

Condition 1: when $M + S1 > \rho(D1 - D2) + S$ and $\frac{1}{6}D1 + (\frac{1}{2} - \rho)D2 - (\frac{2}{3} - \rho)D4 + E > C4 - C3$, E5(0,1,1) is ESS. At this time, the government chooses the no-subsidy strategy, the upstream and downstream enterprises choose the cooperation strategy, and the consumers choose the consumption strategy.

Condition 2: when $\rho(D3 - D4) + S > M + S1$ and $(\frac{2}{3} - \rho)D1 - (\frac{2}{3} - \rho)D3 + E < C3 - C4$, E6(1,0,1) is ESS. at this time, the government chooses the subsidy strategy, the upstream and downstream enterprises choose the non-cooperation strategy, and the consumers choose the consumption strategy.

Condition 3: when $M + S1 < \rho(D1 - D2) + S$ and $(\frac{2}{3} - \rho)D1 - (\frac{2}{3} - \rho)D3 + E > C3 - C4$, E8(1,1,1) is ESS. at this time, the government chooses the subsidy strategy, upstream and downstream enterprises choose the cooperation strategy, and consumers choose the consumption strategy.

The above analysis shows that the evolutionary stabilization strategy is influenced by several parameters and corresponds to different ESS under different constraints.

Table 4. Evolutionary stability results

Balance point	Eigenvalue	Eigenvalue	Eigenvalue	Stability
E1(0,0,0)	$S - S1$	$E + \frac{1}{6}D1 - C4 + C3$	$U4 - D4$	Instability
E2(1,0,0)	$S1 - S$	$E + \frac{1}{6}D1 - C4 + C3$	$U3 + M - D3$	Instability
E3(0,1,0)	$E + S - S1$	$-[E + \frac{1}{6}D1 - C4 + C3]$	$U2 - D2$	Instability
E4(0,0,1)	$\rho(D3 - D4) - M + S - S1$	$\frac{1}{6}D1 + (\frac{1}{2} - \rho)D2 - (\frac{2}{3} - \rho)D4 + E - C4 + C3$	$D4 - U4$	Instability
E5(0,1,1)	$\rho(D1 - D2) + S - M - S1$	$-[\frac{1}{6}D1 + (\frac{1}{2} - \rho)D2 - (\frac{2}{3} - \rho)D4 + E - C4 + C3]$	$D2 - U2$	Fulfillment of Condition 1
E6(1,0,1)	$-\rho(D3 - D4) + M - S + S1$	$(\frac{2}{3} - \rho)D1 - (\frac{2}{3} - \rho)D3 + E - C4 + C3$	$D3 - U3 - M$	Fulfillment of Condition 2
E7(1,1,0)	$-E - S + S1$	$-[E + \frac{1}{6}D1 - C4 + C3]$	$U1 + M - D1$	Instability
E8(1,1,1)	$-\rho(D1 - D2) - S + M + S1$	$-[(\frac{2}{3} - \rho)D1 - (\frac{2}{3} - \rho)D3 + E - C4 + C3]$	$D1 - U1 - M$	Fulfillment of Condition 3

4 Simulation Analysis

The evolutionary stabilization strategy and parameter sensitivity are simulated by MATLAB software. And according to the simulation analysis results, the effects of the initial state on the evolutionary results and the effects of government financial incentives, upstream and downstream enterprises' cooperation incentives, and government subsidies to consumers are explored respectively. In this study, based on the current average level of existing enterprises

development in China, and also combined with related studies, the initial calibration of each parameter variable: $S = 60$, $E = 75$, $S1 = 52$, $\rho = 0.1$, $M = 12$, $C3 = 250$, $C4 = 450$,$D1 = 500$,$D2 = 400$,$D3 = 300$,$D4 = 200$,$U1 = 600$,$U2 = 480$,$U3 = 360$,$U4 = 160$, in million yuan. The sensitivity analysis of the three parameters, such as S1,E,M, is mainly considered, and the corresponding change intervals of each parameter are calibrated as [52, 60], [70, 100], and [12, 20], respectively, assuming that the probability of initial choice of strategy for x, y and z are all 0.2.

Keeping other parameters constant and setting S1 = 52, 54, 56, 58, 60, Figure 2(a) is obtained based on the replicated dynamic equation, as the government increases the amount of subsidy, the longer it takes to reach the active subsidy strategy, and when the subsidy is large enough to exceed a certain threshold, the government finally chooses the no-subsidy strategy. From Figure 2(b), it can be concluded contrary to Figure 2(a) that the amount of reward received by enterprises for active cooperation will promote the government's willingness to actively subsidize. However, comparing Figure 2(a) and (b) reveals that the amount of reward E received by firms for active cooperation promotes their choice of negative subsidy strategy earlier. As shown in Figure 2(c), when the government subsidizes consumers more, it takes longer to evolve to the steady state, especially when M reaches 20, the increase of government consumption subsidy to consumers has a negative effect on the government's choice of positive subsidy strategy instead.

With other parameters unchanged, set S1=52, 54, 56, 58, 60, respectively, based on the replicated dynamic equation to obtain Figure 3(a), the government subsidy amount has little effect on the cooperation of upstream and downstream enterprises, and the final difference is less than 0.1. The possible reason is that the government subsidy amount S1 is not required for the cooperation of enterprises, and the incentive performance of enterprises cooperation is not obvious. The reward amount E=70, 76, 82, 88, 94, 100 is set for the active cooperation of enterprises, and it can be seen from Figure 3(b) that as E increases, the willingness of upstream and downstream enterprises to cooperate will change from "0" to "1", and the larger the value, the more the enterprises The larger the value, the faster the enterprises becomes "1". In order to make more enterprises choose the cooperation strategy, we need to set a reasonable amount of reward for active cooperation to encourage upstream and downstream enterprises to cooperate. Figure 3(c) is the same as Figure 3(a), the amount of consumer consumption subsidy has no effect on the cooperation of upstream and downstream enterprises.

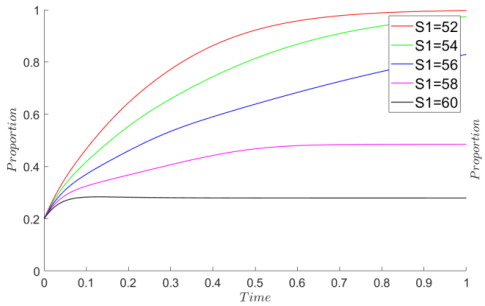

Fig 2(a). Influenced by S1.

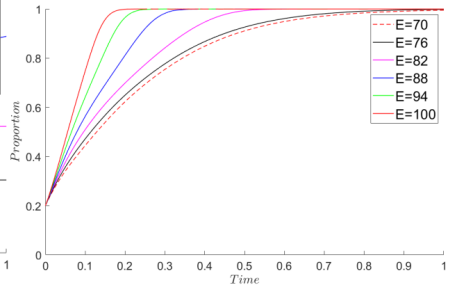

Fig 2(b). Influenced by E.

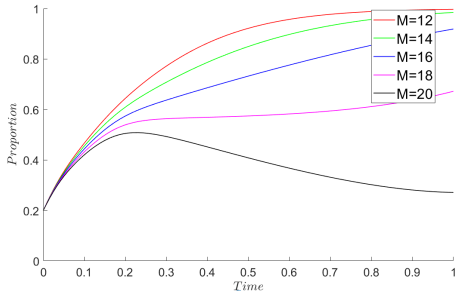

Fig 2(c). Influenced by M

Fig 2. Evolutionary sensitivity analysis of government

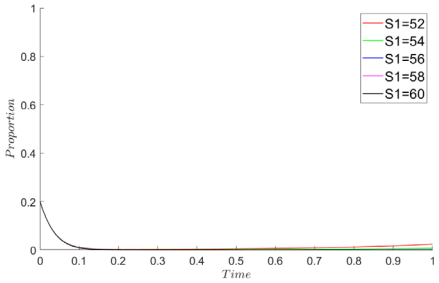

Fig 3(a). Influenced by S1.

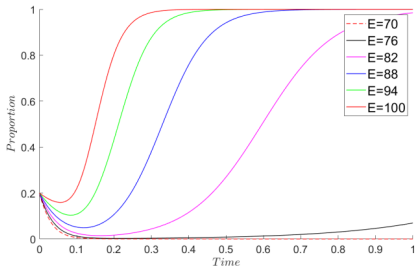

Fig 3(b). Influenced by E.

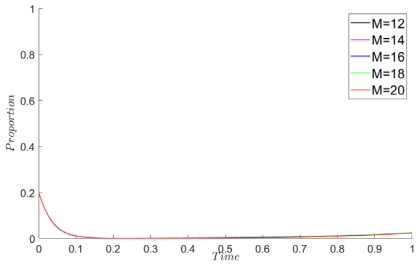

Fig 3(c). Influenced by M.

Fig 3. Evolutionary sensitivity analysis of upstream and downstream enterprises

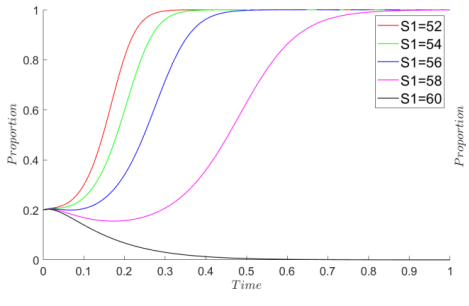

Fig 4(a). Influenced by S1.

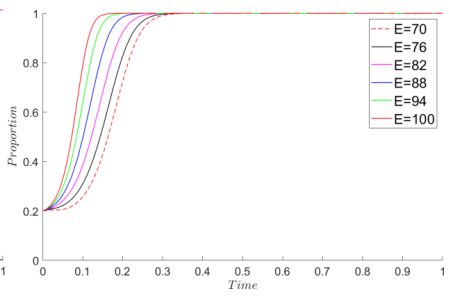

Fig 4(b). Influenced by E.

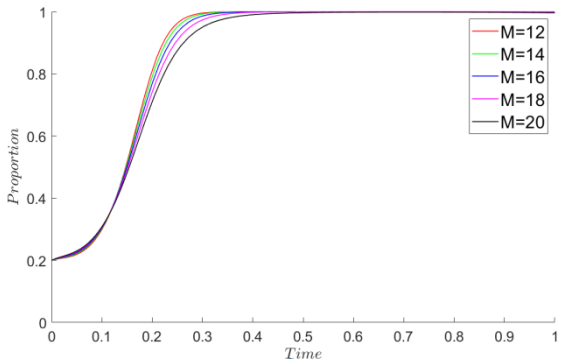

Fig 4(c). Influenced by M.

Fig 4. Evolutionary sensitivity analysis of consumers

Keeping other parameters unchanged and setting S1=52, 54, 56, 58, 60, based on the replication dynamic equation, we get Figure 4(a), when the government subsidies to upstream and downstream enterprises gradually increase, the possibility of choosing the consumption strategy weakens and finally stabilizes in the non-consumption strategy. When the threshold is taken, the trend of the possibility of consumers choosing "1" first becomes more flat and then gradually falls to "0". This may be due to the fact that the subsidies to upstream and downstream enterprises weaken the ability of the government to subsidize consumers, so that consumers' consumption ability is greatly reduced, in the current market environment, the government's subsidies to upstream and downstream enterprises are effective, but the subsidies should be limited to a certain range. e indicates the amount of rewards for active cooperation, as shown in Figure 4(b), as the value of e increases, the curve first reaches "1" the trend of change becomes steeper, which means that consumers have similar psychological motivation with upstream and downstream enterprises, and the higher the reward that the set enterprises get for active cooperation, the more it can stimulate consumers' consumption. The effect of consumer subsidy M on consumer behavior is shown in Figure 4(c). As the value of M increases, the time required for the system to stabilize in the evolutionary process increases. The possible reason for this is that consumer subsidies also weaken the ability to subsidize upstream and downstream enterprises, so that the proportion of groups of compliant enterprises appearing in the market

decreases, thus allowing the amount with consumption to gradually increase. Therefore, the government should also set a reasonable consumer subsidy.

5 Conclusions

In this paper, we construct an evolutionary game model for three stakeholders: government, upstream and downstream enterprises and consumers, and analyze the main factors affecting the participants' decision-making behavior and the potential consequences of evolving behavior. Through numerical simulation of the theoretical model, the following research conclusions are drawn:

(1) After a long-term evolutionary process, the system eventually has three stabilization strategies. The first one is that the government chooses "active subsidy", upstream and downstream enterprises choose "active cooperation" and consumers choose "consumption"; the second one is that the government chooses "no subsidy" and upstream and downstream enterprises choose "consumption". The second is that the government chooses "no subsidy" while upstream and downstream enterprises and consumers respond positively, choosing "active cooperation" and "consumption" respectively; the third is that upstream and downstream enterprises choose The third one is that the upstream and downstream enterprises choose "no cooperation" while the government and consumers respond positively, choosing "active subsidy" and "consumption" respectively.

(2) Subsidies are effective for both upstream and downstream enterprises and consumers, which can make upstream and downstream enterprises change from "non-cooperation" to "active cooperation"; make consumers change from "The subsidies are effective for both upstream and downstream enterprises and consumers. However, excessive subsidies will weaken the financial expenditure and hinder the government's enthusiasm of supervision, so the subsidies should be controlled within a reasonable range.

(3) Considering the factors affecting the strategic choice behavior of upstream and downstream enterprises, the government should increase the basic incentives for cooperative enterprises, so as to improve the market environment. It is worth noting that the impact of basic government subsidies and consumer subsidies can be neglected compared to the base incentives. Therefore, upstream and downstream enterprises can take relevant measures to obtain cooperation incentives, for example, attaching importance to the construction of power battery recycling channels, and integrating more capital into power battery recycling projects through issuing bonds commercial financing and other flexible ways.

(4) The cooperative activities of upstream and downstream enterprises not only rely on the government and enterprises, but also need the extensive participation of consumers, and the government should give consumption subsidies to consumers to promote the circulation of goods. At the same time, improving consumers' consumption ability is crucial to cultivate a good market environment. When consumers believe that consumption can bring reasonable product utility and comfortable living environment, they will pay more attention not only to the price of the products, but also to the economic development they bring.

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